OBSERVATION OF SOLAR COSMIC RAYS FROM OCTOBER 13, 1959 TO FEBRUARY 17, 1961 WITH EXPLORER VII*

by

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ABSTRACT

During the sixteen month period October 13, 1959 to February 17, 1961, twenty-one distinct solar cosmic ray events were observed with Explorer VII (earth satellite 1959 Iota) at high latitudes over North America and Australia in the altitude range 550 to 1100 km. A brief tabular summary is as follows:

TABLE I

Solar Cosmic Rays Observed by Explorer VII

Dates of Event	Approximate Absolute Peak Omnidirectional Intensity of Protons Having E > 30 MeV
November 9, 1959	10 $(cm^2\ sec)^{-1}$
November 30-- December 2, 1959	0.3
January 11-14, 1960	2
March 18-20, 1960	0.3
April 1-2, 1960	210
April 5-6, 1960	5
April 28-29, 1960	26**
April 29-30, 1960	18
May 4-5, 1960	40**
May 6, 1960	13
May 7-8, 1960	25
May 13-14, 1960	40
May 18, 1960	0.8
May 26, 1960	0.8
June 1-2, 1960	5

TABLE I (continued)

Dates of Event	Approximate Absolute Peak Omnidirectional Intensity of Protons Having E > 30 MeV
June 4, 1960	1.3
August 12-16, 1960	2
September 3-9, 1960	250
November 12-15, 1960	12,000 to 46,000
November 15-19, 1960	11,000
November 20-26, 1960	1,800

**Primary peak was missed by Explorer VII.

It is found that the time decay of intensity from its peak value can be represented by t^{-s}, where t is measured from the onset of the apparently responsible solar flare and the value of the exponent s for several cases is as follows: 3.5 for April 28-29; 1.2 for May 4-5; 2.8 for May 13-14; 2.6 for September 3-9; 2 for November 12-15; and 3.4 for November 15-19, 1960.

The latitude dependence of solar cosmic ray intensity at various longitudes and for both Northern and Southern Hemispheres has been studied for ~~five~~ eight of the major events which yielded sufficient data for definitive analysis. Such bodies of data exhibit a chaotic pattern when plotted against traditional geomagnetic cut offs such as those of Quenby and Webber but are systematized in a coherent manner when plotted against the magnetic shell parameter L of McIlwain.

L_{min}, the minimum value attained by 30 MeV protons, is strongly and systematically depressed during the main phase of geomagnetic storms. The correlation coefficient between L_{min} and U is -0.88 and between L_{min} and H is +0.88, where U is the Kertz parameter which gives a measure of the equatorial ring current and H is the horizontal component of the geomagnetic field (at Tucson). The observed L_{min} of 5.2 during quiet periods implies the existence of a quiescent ring current.

Part I

DETECTION AND INTENSITY MEASUREMENT OF
SOLAR COSMIC RAYS WITH EXPLORER VII

1. Introduction.

This part provides a summary of solar cosmic ray intensity observations at high latitudes over North America and Australia in the altitude range 550 to 1100 km during the period October 13, 1959 to February 17, 1961. Data are derived mainly from telemetry receptions at Iowa City, Iowa; Ottawa, Canada; and the NASA stations at Blossom Point, Maryland; San Diego, California; and Woomera, Australia. The observations were made with an apparatus comprising two Geiger-Mueller tubes prepared in this laboratory by Ludwig and Whelpley [1960] and flown in the I.G.Y.-Composite Satellite Explorer VII (1959 Iota) which was developed by the U. S. Army Ballistic Missile Agency (now the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration). The successful, long-term operation of this equipment in orbit has provided unique, homogeneous set of observations on solar cosmic rays by the satellite technique which was first used successfully by Rothwell and McIlwain [1959]. Satellite observations excel those by other commonly used techniques in providing absolute intensities above the atmosphere; detailed dependence of intensity on latitude; and homogeneous quasi-continuous data for long periods of time with a single set of instruments.

Table I provides a brief tabular summary of solar cosmic ray events observed by Explorer VII during the observational period and Table II reviews the properties of the two Geiger tube detectors in the instrument [Van Allen and Lin, 1960]. No analysis of the solar cosmic ray beam into its components (i.e., protons, alpha particles, heavy nuclei, and electrons) is provided by this equipment. The presumption of the present paper that the beam consists predominantly of protons is based on the extensive work of other investigators, not detailed herein.

2. Analysis of Observations.

The method of analyzing data is similar to that previously reported [Van Allen and Lin, 1960]. Since then it has been found by examination of counting rate data under high intensity conditions during the November 1960 solar cosmic ray events and during passages through the inner radiation zone that the apparent counting rate of the 112 Geiger-Mueller tube saturated at a considerably lower value than that found by Ludwig and Whelpley [1960] in pre-flight calibration. The apparent counting rate of the 302 tube also saturated at a lower value. Because the 302 tube has a considerably smaller geometric factor than that of the 112 tube, and because the

TABLE II

Properties of SUI Detectors in Explorer VII

Detector	ϵG_o *	Absorbers over 70% of Solid Angle		Approximate Detection Thresholds: Proton	Electron,+ extrapolated range	X Rays, 5% transmission
Anton type 112 Geiger Tube Scaling Factor: 128	7.2 cm^2	Stainless steel	0.040 g cm^2	30 MeV	2.5 MeV	80 keV
		Al	0.26			
		Pb	1.15			
		Mg	0.14			
Anton type 302 Geiger Tube Scaling Factor: 2048	0.54	Stainless steel	0.40	18	1.1	30
		Mg	0.14			

*Counting rate of tube for penetrating particles is equal to ϵG_o times omnidirectional intensity J_o.

+For non-penetrating electrons, see L. A. Frank [1962].

additional shielding of the 112 tube has little effect in absorbing the radiation encountered in the lower edge of the inner radiation zone near the equator, it was possible to construct an approximate curve of apparent rate vs true rate of the 112 tube by using in-flight data.

This curve was then checked and refined by an extended study of the characteristics of the spare flight unit of Explorer VII apparatus. The parameters which influence the saturation characteristics of the two counting rates are the temperature, the supply voltage to the amplifiers, pulse formers, and scalars (nominal value 6.5 v), and separately the high voltage supply voltage for the tubes (nominal 700 v). Some sample results on the spare payload are as follows:

Circuit Voltage	High Voltage	Saturation Counting Rate of 112 Tube
(a) 4.05 volts	630 volts	305 counts/sec
(b) 5.35	630	385
(c) 5.20	640	515
(d) 6.00	700	930

Full characteristic curves of apparent vs true counting rate were run for each of the above conditions to correspond to various flight conditions as shown in Figure 1.

The saturation counting rate of the 112 tube, as observed during passages through the inner radiation zone, has been plotted vs time from the day of launching of the satellite to the end of December 1960 [Lin and Venkatesan, Private Communication, 1962].

The time variation of the saturation counting rate is well correlated with the time variation of the (independently telemetered) temperatures of the transmitter package and the battery package in the satellite. The latter quantities are, in turn, well correlated with the calculated average exposure to sunlight. The foregoing three-fold correlation lends plausibility to the belief that the observed long-term variations of saturation counting rate of the 112 as well as the diurnal fluctuations (typically some 60 counts/sec maximum to minimum fluctuation about a mean value of about 300 counts/sec) are attributable to the composite effects of varying temperature and of varying state-of-charge of the chemical batteries which are charged by an array of solar cells.

It should be emphasized that if the apparent counting rate of the 112 is below 100 counts/sec, the true counting rate has only a slight dependence on the saturation characteristics of the system and if it is below 50 counts/sec, it has no dependence (cf., Figure 1). Thus, most of the data of the present paper are independent of the foregoing uncertainties. Only the high counting rate data of early April, early September, and mid-November 1960 have required special treatment. In these cases a selection among the curves of

Figure 1 has been made on the basis of contiguous passes through the inner zone near the equator. In some cases, e.g., the November events, data from the 302 tube (which had a much higher saturation level) have been invoked. But most of the results herein are based on the corrected counting rates of the 112. Previously published absolute intensities for the April 1, 1960 event are corrected in the present paper.

The best estimates of the solar (and galactic) cosmic ray intensity are obtained from observations during the portions of the satellite's orbit which are at the highest geomagnetic latitudes or more precisely at the highest values of the L parameter. (See McIlwain, 1961, and Van Allen, 1962, for definition and discussion of the L parameter.) In this way counting rates having the smallest possible contribution from trapped particles in the outer radiation zone are obtained. To obtain the net counting rate due to the penetrating particles (i.e., cosmic rays, in contrast to the soft trapped radiation) the following procedure was used:

(a) A large body of observations of the apparent counting rates of the 112 tube, N_{112}, and of the apparent counting rate of the 302 tube, N_{302}, were assembled for quiescent (non-solar event) conditions and for the highest available latitudes.

(b) To the extent necessary these data were corrected for dead time to yield the respective true rates N^*_{112} and N^*_{302}

($N^*_{302} = N_{302}$ if $N_{302} < 1000$ counts/sec). For data shown in Figure 2, the dead time corrections were trivial.

(c) A plot shown in Figure 2 was then made of N^*_{112} vs N^*_{302}. From this plot it is seen that N^*_{112} is a linear function of N^*_{302} and that as $N^*_{302} \longrightarrow$ zero, N^*_{112} approaches 14.2 counts/sec. Since the ratio of geometric factors (cf. Table II) for penetrating particles, i.e., ordinary cosmic rays, is 13.3, and $N^*_{112} = 14.2$ corresponds to $N^*_{302} = 1.08$. Hence, the intercept at $N^*_{302} = 1.08$ is taken as the rate of the 112 tube, due to galactic cosmic rays and their charged particle albedo from the atmosphere. The equation of the curve for Figure 2 is:

$$N^*_{112} = 14.2 + 0.119\, N^*_{302}$$

or

$$\frac{N^*_{112} - 14.2}{N^*_{302}} = 0.119.$$

This ratio is similar to that usually observed in the high-intensity soft radiation region of the outer radiation zone, thus further supporting the belief that Figure 2 can be used reliably in subtracting the contribution of soft radiation to the rate of 112 tube. It is evident from the latitude dependence of the counting rates of the two tubes that the time-varying outer boundary of the outer radiation zone is the principal cause of the variation of the counting rates at high latitudes. The use of Figure 2 makes it possible to increase considerably the sensitivity for the reliable detection of solar cosmic rays. When N^*_{302} is less than, say 100 counts/sec, one can measure an intensity of solar cosmic rays as low as 2 particles $(\mathrm{cm}^2\ \mathrm{sec})^{-1}$; in special cases (cf. Table I), it has been possible to extend the sensitivity down to 0.2 $(\mathrm{cm}^2\ \mathrm{sec})^{-1}$.

Three examples of the analysis of observations in the above manner follow:

(a) In the pass which covered from 0718 to 0736 U.T. on November 18, 1959, shown in Figure 3, the position of observation was chosen at 0729.5 U.T. at which the satellite reached the highest latitude. N_{302}, the apparent counting rate of the 302 tube, is 17 counts/sec; and N_{112}, the apparent counting rate of the 112 tube, at the same time, is 16 counts/sec. From the curve of apparent counting vs true counting rate for the 112 tube shown in Figure 1, one finds the true counting rate N^*_{112}, corresponding to $N_{112} = 16$ is also 16. By Figure 2 and the above discussion, the estimated contribution of soft trapped radiation in the outer edge of the outer radiation zone to the counting rate of the 112 tube is:

$$\Delta N^*_{112} = 0.119\ N^*_{302} = 2 \text{ counts/sec.}$$

The net true counting rate due to cosmic radiation is taken to be:

$$N^{**}_{112} = N^{*}_{112} - \Delta N^{*}_{112} = 14.0 \pm 1.0 \text{ counts/sec.}$$

(b) In the pass which covered from 2347 on April 27, 1960 to 0005 U.T. on the following day (Figure 4) the time of observation was chosen at 2355 U.T. when $N_{112} = N^{*}_{112} = 14$ and $N_{302} = 4$. The correction term N^{*}_{112} is less than 0.5 count/sec; therefore, it was neglected but was included in the error; thus we have:

$$N^{**}_{112} = 14.0 \pm 1.0 \text{ counts/sec.}$$

(c) On April 28, 1960 (Figure 5) in the pass which covered from 2323 to 2342 U.T. (after the flare on April 28), the time of observation was taken at 2332 U.T. when $N_{302} = 12$ and $N_{112} = 72$ counts/sec. During the period of 27-30 April the inner radiation zone data showed that the saturation counting rate of the 112 tube during this period was between 250 to 320 counts/sec; thus a fairly dependable corrected value N^{*}_{112} may be read from curve (a) in Figure 1 as $N^{*}_{112} = 95$ counts/sec, and $\Delta N^{*}_{112} = 0.119 \times 12 = 1.4$ counts/sec. Thus $N^{**}_{112} = 94 \pm 10$ counts/sec. The error estimate is intended to represent the overall uncertainty in the correction procedure. During large solar cosmic ray events there is an important (and sometimes dominant) contribution to N^{*}_{302} due to solar cosmic rays. Fortunately, in such cases there is usually an accompanying depletion of the outer radiation zone [Van Allen and Lin, 1960] such that the correction for trapped radiation may be negligible. In solar cosmic ray events of intermediate size, say 20 times galactic cosmic ray intensity, when ΔN^*_{112} is not negligible compared to N^*_{112} the final value of N^{**}_{112} is determined by a two stage iteration process, i.e., by first using Figure 2 to find ΔN^*_{112}, then taking $(N^*_{112} - \Delta N^*_{112})$ and the relative geometric factor of the 112 tube and 302 tube to estimate the penetrating contribution to N^*_{302}, and finally Figure 2 again to get an improved ΔN^*_{112} and thereby an improved N^{**}_{112}.

An estimate of the overall uncertainty of each N^{**}_{112} was made on the following basis:

(a) The fluctuations of N_{112} near the observation point and the basic statistical uncertainty;

(b) The uncertainty attendant on the use of a selected curve of Figure 1 in correcting for system dead time to obtain N^*_{112}; and

(c) The uncertainty in subtracting the contribution of soft trapped radiation by means of Figure 2 to obtain finally the true, net counting rate due to penetrating particles N^{**}_{112}.

There remains, potentially, a systematic error in the results due to the time-variable aspect of the equipment with respect to earth-fixed coordinates. The S.U.I. package was mounted on the extreme forward end of the payload with about 70% of the solid angle at the Geiger tubes lightly shielded (cf. Table II) and the remaining 30% heavily shielded by the bulk of the payload. The axes of the Geiger tubes were orthogonal to the spin axis of the payload. The payload had an in-flight spin rate of about 6 cycles/sec (slowly damped) and the forward drawn axis pierced the celestial sphere at right ascension $(303 \pm 5)°$, a declination + $(30 \pm 5)°$,-for at least the first two months of its flight [Naumann, 1962] and probably for a much longer period.

If solar cosmic rays arrive near the earth in sharply directional beams, the resulting counting rates would be expected to vary markedly with longitude and to be markedly different over the Northern and Southern Hemispheres of the earth on contiguous passes due to the shadowing of the detectors of the bulk of the payload (average of some fifteen grams/cm^2). No such effects have been apparent though the matter has not been studied exhaustively. It is tentatively concluded that this matter does not lead to significant errors, a conclusion which is strengthened by the observations by others in the broad angular distribution of low energy solar cosmic rays near the earth [Ogilvie, Bryant, and Davis, 1962].

3. Observational Data and Discussion.

During the sixteen months of observation values of N^{**}_{112} at high latitudes have been obtained for over 1000 passes (both Northern and Southern Hemispheres) and tabulated in detail [Lin, 1961]. The vast majority of these values cluster about a mean of 14.5 counts/sec, corresponding to an omnidirectional intensity J_o = 2.0 particles/cm^2 sec. This intensity is interpreted as that of galactic cosmic rays and their charged-particle albedo arising in atmospheric interactions. A separate discussion of the observations of galactic cosmic rays as a function of latitude and of time is contained in a separate paper.

The occurrence of solar cosmic rays is revealed by the positive departure of N^{**}_{112} at high latitudes from its mean quiescent value there and, in favorable cases, by the latitude dependence of this departure. The highest geographic latitude reached by Explorer VII is 50.5°, corresponding to a geomagnetic latitude of about 61° over North America. It is conceivable that further solar cosmic ray events might have been detected at higher latitudes. But comparison of Table I herein with the listing of PCA events by Bailey [1962] shows (a) that Explorer VII technique is a more sensitive one for the detection of solar cosmic events than is the present VHF ionospheric scatter technique on a propagation path across the polar cap, and (b) that perhaps only the "very small" events reported by Bailey on 29-30 March 1960 were inaccessible to Explorer VII during the period of its observations.

Figures 3 and 4 are representative plots of observations on days when solar cosmic rays are absent; and Figures 5 and 6, when they are present.

A brief account of Explorer VII observations of solar cosmic rays and auxiliary data follows:

<u>November 9, 1959 Event.</u>

The first case during the observation period of Explorer VII that N^{**}_{112} exceeded 20 counts/sec was around 1051 U.T. on November 9, 1959 during the pass which covered the period 1042 U.T. to 1058 U.T. N^{**}_{112} was 30 $\pm$ 5 counts/sec. During the following pass, which covered the period 1230 U.T. to 1240 U.T. on the same day, the counting rate curves of both the 112 and the 302 tubes exhibited simultaneous bumps in the high latitude portion of their counting rate vs time curves in the region where both curves usually exhibit valleys. The bumps were narrower than those for usual solar cosmic ray cases, and hence indicate an unusually high latitude threshold or an unusually soft spectrum. At the highest value of latitude N^{*}_{302} = 107 and N^{*}_{112} = 90. The resulting N^{**}_{112} is 85 $\pm$ 9 counts/sec. Hence the radiation being detected was considerably harder than typical outer zone radiation but considerably softer than that in a typical solar cosmic ray event. After subtracting the contribution of galactic cosmic rays (14.5 counts/sec), a net intensity of 10 $(cm^2\ sec)^{-1}$ is found from the 112 tube data at the highest latitude (longitude -94.8°, latitude +49.3°, altitude 633.1 km) at 1234.7 U.T., on the assumption that the particles being counted are directly penetrating ones, i.e., protons of $E > 30$ MeV. The latitude dependence leaves little doubt that the primary radiation must consist of charged particles, though, as remarked above, the Explorer VII data do not determine the nature of the particles.

<u>November 30-December 2, 1959</u>.

Explorer VII data showed an increased counting rate of about 10% to 30% above normal cosmic ray intensity beginning early on November 30 and continuing through early December 2. The intensity had returned to normal by late December 2. During the period 2300 on December 3 to about 0330 U.T. on December 4 a Forbush decrease of about 20% was observed with a gradual recovery to normal by December 7.

The optical flare of importance 3 which may be responsible for the solar cosmic rays was observed at Sacramento Peak on November 30 beginning at 1722 U.T. and ending at 1904 U.T. at location N08E06 [Natl. Bur. Standards, U.S., 1960].

At the ground observatory at Deep River [Natl. Bur. Standards, U.S., 1960] the neutron monitor showed no significant increase of intensity during the period in which Explorer VII observed the increases. The onset of the Forbush decrease was observed there at about 0000 hour U.T. on December 3. The maximum decrease of about 5% was observed about 24 hours later. Recovery was substantially complete by early December 7. This time history of the Forbush decrease was in good agreement with what Explorer VII observed although the onset of the Forbush decrease was not clearly defined by Explorer VII data.

<u>January 11-14, 1960</u> (Figure 8).

At 2040 U.T. on January 11, 1960 the beginning of an optical flare of importance 3 at the location N23E03 was observed at the Lockheed Observatory. The end was at 2355 U.T. [Natl. Bur. Standards, U.S., 1960].

Explorer VII data showed that during the middle of January 10, after the storm sudden commencement (SSC) at about 0600 U.T. on January 10 N^{**}_{112} was 14 $\pm$ 1 (normal cosmic ray value). During the middle of January 11, before the above solar flare of January 11 was observed, N^{**}_{112} was about 17.5 $\pm$ 2.0, possibly somewhat increased. By the middle of January 12, N^{**}_{112} was 27, corresponding to an excess particle intensity of 2 $(cm^2\ sec)^{-1}$. Thereafter, the intensity decreased gradually and was back to normal by about the middle of

January 15. There was no increase in intensity observed by the B211 Deep River Neutron Monitor, but a 4% to 5% Forbush decrease was recorded during January 14 to 19, with the onset at about 1900 U.T. on January 13, at about the same time as a geomagnetic storm sudden commencement. This Forbush decrease was not observed by Explorer VII, possibly because it was marked by lower energy solar particles.

March 18-20, 1960.

N^{**}_{112} increased by 10 to 20 percent above the normal cosmic ray value during this period. The increase, which does appear to be significant, has not been identified with any other reported phenomenon.

April 1-2, 1960, and April 5, 1960 (Figure 9).

A report on these events has been given previously [Van Allen and Lin, 1960], including the report of a 24 percent Forbush decrease during the early morning of April 1.

An improved estimate of the maximum intensity on April 1 has been made with the help of the set of laboratory curves (Part 1-2 and Figure 1) of apparent rate vs true rate of the 112 tube. The choice among the family of curves to be used was made by finding the flight saturation value of the 112 tube in nearly inner radiation zone passes at a similar local time. The saturation value adopted was 340 counts/sec.

The resulting value of N^{**}_{112} at 1023 U.T. on April 1 was 1600 counts/sec. This yields

$$J_o = 220 \pm 30 \ (cm^2 \ sec)^{-1}$$

for the omnidirectional intensity of solar protons of energy greater than 30 MeV. At the same time the counting rate of the 302 tube yields

$$J_o = 210 \pm 20 \ (cm^2 \ sec)^{-1}$$

of protons of energy greater than 18 MeV. The combination of these two results indicates that the spectrum was not rising appreciably between 30 and 18 MeV and hence invalidates the earlier spectral remark of Van Allen and Lin [1960, p. 300, top of column 2].

The peak intensity of the April 5-6 event was not observed by Explorer VII. At 1000 U.T. on April 5 the omnidirectional intensity of protons of $E > 30$ MeV was 5 $(cm^2 \ sec)^{-1}$.

<u>April 28-30, 1960</u> (Figures 4, 5, 6, 7, 10, 17, and 18).

Figures 4 through 7 show sample data from Explorer VII before, during, and after the proton event. Figure 4 is a typical set of observations at non-solar proton time, while Explorer VII was over North America. The first peak in intensity was recorded as the satellite cut through the outer radiation zone during the north bound pass to higher latitude. The second peak was recorded as the satellite returned through the outer radiation zone during the south bound pass. Figure 4 was recorded during the period 2347 U.T. on April 27, 1960 to 0006 U.T. on the following day, about 90 minutes before the flare of importance 3 was observed at 0130 U.T. on April 28 [Natl. Bur. Standards, U.S., 1960]. The location of the flare was S05E34. The satellite data show a slight increase (N^{**}_{112} = 19.0 ± 2.0 counts/sec) at the highest latitude at 0323 U.T. The time dependence of the solar proton intensity of this event is shown in Figure 10. The detection time by Explorer VII of solar protons beginning to arrive in the vicinity of the earth almost coincided with the onset of polar cap absorption of greater than 1 decibel, recorded at Thule, Greenland [Leinbach, 1960]. There were no further satellite data until 1920 U.T. which gave the maximum intensity detected by Explorer VII for this event. The following passes show a decreasing intensity. Hence, it is clear that the peak of the event was not observed. The proton omnidirectional intensity with $E > 30$ MeV at 1920 U.T. was 26 $(cm^2\ sec)^{-1}$. The intensity decreased monotonically with time to an omnidirectional intensity of 7 $(cm^2\ sec)^{-1}$ at 0300 U.T. on April 29. Figure 5 was recorded during 2323 to 2342 U.T. on April 28. This pass shows the solar protons detected by the 112 tube.

The time scales are chosen such that if Figures 4 and 5 are superimposed the positions of the satellite are about the same at all points; e.g., the position of the satellite at 2350 U.T. on April 27 is about the same as that at 2327 U.T. on April 28, and at 2355 U.T. on April 27 about the same as that at 2332 U.T. on April 28. Figures 4, 5, 6, and 7 are plotted in the same way, e.g., the position of the satellite at 2350 U.T. on April 27 is about the same as that at 2240 U.T. on April 30, 1960 (Figure 7). The increase of intensity recorded by the 112 tube in the higher latitude part (between the two peaks) is clearly seen by comparison of Figure 5 with Figure 4, and the latitude dependence of the intensity is shown well in Figure 5. This event was also registered by the Soviet group with balloon equipment [Charakhch'yan, Tulinov, and Charakhch'yan, 1961]. Comparing Figures 4 and 5, one finds that there was a marked decrease in intensity of the outer zone during that period [Forbush, Pizzella, and Venkatesan, 1962]. Such a low intensity in the outer zone enhances the opportunity to study the latitude dependence of the solar cosmic ray intensity. In many cases, the intensity in the outer radiation zone under magnetically disturbed conditions is much lower than that shown in the first peak in Figure 5. The latitude dependence of the arrival of solar cosmic rays is discussed in Part II of this paper. The intensity of solar cosmic rays (non-latitude dependent part) observed during the period 1854 to 1859 U.T. on April 29 was 5 $(cm^2\ sec)^{-1}$ (Figures 10 and 18). The ratio of the solar proton intensity with $E > 18$ MeV to that with $E > 30$ MeV is estimated to be about 1.4 during late April 28 and early April 29. The increased intensity during late April 29 and early April 30 was presumably due to flares beginning at 0107 U.T. and ending at 0230 U.T. at N12W20, and also beginning at 0612 U.T. and ending at 0822 U.T. on April 29 at N15W20, observed at Lockheed and Capri S respectively. Type 4 radio noise was observed at 0346-0709 U.T. on April 29. The solar proton intensity increase of April 29 followed several hours after the flare. The unusually long delay time may well be explained by the following [Obayshi, 1962]: Solar protons ejected from the flare of April 29 were stopped and trapped by the magnetic plasma cloud near the mid-point of the sun-earth line, which had been produced by the flare of April 28. However, some particles, presumably of higher energy, leaked out through the magnetic plasma cloud, and this leakage may account for a slow rise in flux until the arrival of the cloud which is observed at the time of SSC early April 30.

The data recorded from 2259 to about 2318 U.T. on April 29 is shown in Figure 6. Comparing with Figures 4 and 5 we see that the intensity in the outer zone increased relative to that shown in Figure 5 while the latitude dependent part of the solar cosmic ray intensity was partly observed by trapped particles in the outer zone. Therefore, these data were not shown in Figure 18, but the value of N_{112}^{**} at the highest latitude was taken at 2310 U.T. yielding $N^{**}_{112} = 79 \pm 10$ counts/sec. During the pass from 2235 U.T. to 2255 U.T. on April 30 shown in Figure 7, no solar protons were detected and the intensity in the outer zone had decreased markedly. A summary of the observational results associated with the solar flare of April 28 follows:

(a) A flare of importance 3, located at S05E34, was observed at Hawaii beginning at about 0130 U.T. and ending at about 0145 U.T. on April 28. Solar flare produced particles continued to arrive in the vicinity of the earth for more than 22 hours after optical evidence of the solar flare had ceased.

(b) The omnidirectional intensity J_o ($E > 30$ MeV) declined with elapsed time t after the optical onset of the flare as $t^{-3.5}$ for the interval $8 < t < 22$ hours. The peak intensity was not observed and there is, of course, no foundation for extrapolating the above empirical relationship to times t less than 8 hours.

(c) The time history of the latitude-independent corrected rate, N^{**}_{112}, at high latitudes is plotted in Figure 10. Data points from interleaved passes over North America and Australia are well represented by a single curve, thus exhibiting independence of local time.

(d) A Forbush type decrease of galactic cosmic ray intensity of about 13% was observed by the satellite at around 2100 U.T. on April 30, and about 5% during May 1. No significant increase was observed by the ground neutron monitor at Deep River during the solar proton events. However, the neutron monitor showed that a maximum of about 5% of Forbush decrease was observed around 2200 U.T. on April 30 after which the intensity recovered gradually during the following day. The Russian group reported that the integral energy spectrum of solar protons on April 28 was $E^{-5.5}$ for 220 MeV $<$ E $<$ 300 MeV. The slope is less steep in the range of 175 MeV to 220 MeV [Charakhch'yan et al., 1962, page 532, Figure 3]. Unfortunately, the exact time of their observation was not shown in their paper; therefore, it is not possible to use our observations to extend the energy spectrum down to 30 MeV.

May 4-8, 1960 (Figures 10, 15, 19, 20, 21, and 22).

The May 4, 1960 solar cosmic ray event has been reported elsewhere [Palmeira and McCracken, 1960; Rose, 1960; Santochi, Manzano, and Roederer, 1960; Maeda, Patel, and Singer, 1961; Winckler, Masley, and May, 1961; Biswas and Freier, 1961; Charakhch'yan, Tulinov, and Charakhch'yan, 1961; McCracken, 1962b], as observed with balloon equipment and ground neutron and meson monitors.

A 3^{+} solar flare, accompanied by radio bursts and intense type IV radio continuum, was observed at 1015 U.T. on the western limb of the sun [Natl. Bur. Standards, U.S., 1960].

No other flares of an importance greater than 1^+ were observed before the 3^+ flare of May 4. Therefore it is believed that the 3^+ solar flare is responsible for the May 4 event. The first arrival of solar cosmic rays associated with the flare was observed at 1029 U.T. by the ground neutron monitors [McCracken, 1962b]. If one assumes that the solar protons were ejected at the beginning of the solar flare then the actual flight time of solar protons to travel from the sun to the earth is about 22 minutes. The rectilinear flight time for protons of 500 MeV (~ 1.1 BV) and 1 BeV (~ 1.7 BV) from the sun to the earth are 10.5 minutes and 9.2 minutes, respectively. The effective atmospheric cut off rigidity for a sea-level neutron monitor is approximately 1.1 BV [McCracken, 1962a]. Therefore, the ratio of the actual flight time to the rectilinear flight time is about 2. The ratio for lower energy particles observed during April 1, 1960 event was also about 2 [Van Allen and Lin, 1960] and the similar result for February 23, 1956 event [see Carmichael, 1963]. However, many observational results indicate that this ratio of 2 should be taken as the lower limit. The result would immediately imply that the minimum flight path is about twice that of the distance between the sun and the earth.

From the study of neutron intensity enhancements observed by the stations within the polar cap regions of the earth during the flare effect of May 4, McCracken [1962b] concluded that the incidence of particles on the earth was highly directional. Unfortunately, there were no data from Explorer VII during the anisotropic phase of the incident solar cosmic rays due to the absence of a suitable pass.

Explorer VII data first showed an increased N^{**}_{112} from normal cosmic ray intensity at 1516 U.T. During the following pass at 1700 U.T. the incremental omnidirectional intensity was about 16.5 $(\text{cm}^2\ \text{sec})^{-1}$, 8 times normal cosmic ray intensity. However, the maximum intensity of the outer zone detected by Explorer VII, during the pass around 1516 U.T. on May 4, was at $L = 2.7$, while the L value above which the omnidirectional intensity was independent of latitude in J_o vs L plots during May 4 was greater than 5 earth radii. Therefore, our measurement of intensity at $L = 3.5$ and 4.4 at 1516 U.T. and 1700 U.T., respectively, were not on the flat high latitude portion of counting rate vs L plots and could not be included properly in Figure 10. In Figure 10 all the data points were taken from the latitude independent portion of counting rate vs L plots.

Total ionization and counting rate measurements were made at 6 g/cm^2 depth at Minneapolis ($L = 3.26$) in the period from 7 to 16 hours following the cosmic ray flare of May 4. The omnidirectional ionization and counting rates were about 25 percent above normal and the ionization ratio per particle was 1.2 times that of normal galactic cosmic rays at the same altitude. It was concluded that the primary particles producing the effects measured lie, on the average, in the high energy range [Winckler, Masley, and May, 1961]. However, in the higher latitudes, say $L > 5$, protons with energies at least down to 18 MeV were detected by Explorer VII. The Explorer VII data at 1842 U.T. on May 4, of 40 $(cm^2\ sec)^{-1}$ yielded an intensity of solar protons with $E > 30$ MeV, which was the maximum intensity observed in this event. However, this maximum observed intensity is probably considerably lower than the true peak intensity of this event since the subsequent passes show a steady decrease of intensity (Figure 10). From 302 tube data, the omnidirectional intensity with $E > 18$ MeV was estimated roughly to be 52 $(cm^2\ sec)^{-1}$ at 1842 U.T. The integral energy spectrum obtained by Charakhch'yan et al. [1961] for the May 4 event was $E^{-2.2 \pm 0.2}$ for $200 < E < 400$ MeV. Since their measured energy spectra are average value, it is not possible to extend the energy spectrum down to 30 MeV by using the results obtained by Explorer VII.

The time decay of intensity was according to $t^{-1.2}$ for $8 < t < 30$ where as above t is measured in hours from the onset of the flare. This result is close to $t^{-1.35}$ obtained by the Soviet group [Charakhch'yan et al., 1961] but is different from t^{-2} obtained by Winckler, Masley, and May [1961]. It seems that the decay is a function of energy which conclusion was also obtained from observations of the April 1, 1960 event [see Webber, 1962].

The increase of proton intensity shown in Figure 10 on May 6 was presumably due to a flare of class 3 beginning at 1404 U.T. at S10E08 [Natl. Bur. Standards, U.S., 1960]. The burst of solar cosmic rays detected by Explorer VII was in close coincidence with the onset of the PCA [Leinbach, 1960]. The increase of intensity on late May 7 cannot be associated with any flare of importance greater than 1^+, nor was any magnetic storm or Forbush decrease observed during May 7. Since the proton intensity was already declining on late May 6 and was lower than the intensity observed during late May 7, it is presumed the late May 7 increase might be due to a flare on the back side of the sun.

A 10% Forbush decrease was observed on the ground around 2000 U.T. on May 8 but the Explorer VII rates were only slightly lower than background, possibly because of a superposition of the low intensity tail of the solar flare particles and the decreased galactic intensity.

The conclusions from the observation of these events are:

(a) The peak intensity of the May 4 event was not observed with Explorer VII but the omnidirectional intensity of protons with $E > 30$ MeV at about 1840 U.T. approximately 8 hours after the beginning of the optical flare, was 40 $(\text{cm}^2\ \text{sec})^{-1}$, 20 times that of galactic cosmic rays. The time decay of the omnidirectional intensity during the period of observation is $t^{-1.2}$.

(b) The time of observation of solar protons associated with the May 4 flare was more than 30 hours.

(c) The intensity increase on May 6 was due to the flare occurring on May 6 but the increase during the late May 7 is presumably due to a flare occurring on the other side of the sun.

(d) No significant Forbush decrease was observed by Explorer VII at around 2000 U.T., but one was observed on the ground. This is presumably due to masking by solar flare particles.

<u>May 13-14, 1960</u> (Figures 10, 16, and 23).

Explorer VII data received from Woomera show an increase of intensity from cosmic ray background of N^{**}_{112} = 15 counts/sec to N^{**}_{112} = 58 counts/sec at 1330 U.T. on May 13. This data point is not included in Figure 10, since at the highest latitude reached by the satellite during this time, the local geomagnetic cut off was higher than the instrumental threshold. It is believed therefore that the peak intensity of this event was not observed.

All the passes of Explorer VII before 1330 U.T. on May 13 did not provide information on high latitude observations. The flare which is presumed to be responsible for this event was observed by several observatories at 0522 U.T. and of importance 3^+ at the location of N30W64 [Natl. Bur. Standards, U.S., 1960]. The onset time of polar cap absorption was recorded at about 0800 U.T. at Thule, Greenland [Leinbach, 1960]. At 1512 U.T. N^{**}_{112} was 305 counts/sec, corresponding to 40 $(cm^2\ sec)^{-1}$ the omnidirectional intensity of solar protons with $E > 30$ MeV, about 20 times cosmic ray background. The ratio of the proton intensity with $E > 18$ MeV to that with $E > 30$ MeV at about 1500 U.T., 1700 U.T. 1840 U.T. on May 13 are about 70 to 39, 70-35, and 56-28 respectively.

The time dependence of N^{**}_{112} is shown in Figure 10. The decline of the omnidirectional intensity J_o of solar proton with $E > 30$ MeV, has the form $t^{-2.8}$ up to an elapsed time of at least 30 hours. Values of N^{**}_{112} taken both from the Woomera, Australia and North American stations lie along the same curve (Figure 10), implying that the protons are isotropic in direction. This event was not observed by ground neutron monitors.

N^{**}_{112} was back to the normal value of 14.5 counts/sec sometime before 1600 U.T. on May 15.

<u>May 18 and May 26, 1960</u> (Figure 11).

On May 18 after 1200 U.T. an increase of about 40% above the normal cosmic ray intensity was observed by Explorer VII. About the same amount of increase was observed around 1200 U.T. on May 26. During May 17 and 18, there were no solar flares of importance greater than 1^+. Therefore, the increase may be due to small flares of importance not greater than 1^+ or to flares on the back side of the sun. During May 26 there was a flare of importance 2^+ beginning at about 0830 and ending at about 1000 U.T. This flare may be responsible for this small solar proton event, and responsible for the subsequent Forbush decrease observed on the ground during late May 28 to June 1 with onset time at about the same time as the storm sudden commencement reported at 2019 U.T. on May 28.

June 1 to June 4, 1960 (Figure 11).

This event, although of low intensity was very interesting. On June 1, a flare of importance 3^+ was observed at the Capri S observatory [Natl. Bur. Standards, U.S., 1960], starting at 0824 U.T. and ending at 1340 U.T. at the location N28E46. This flare was presumably responsible for ejecting solar protons and solar plasma causing a magnetic storm with storm sudden commencement at 1731 U.T. on June 3, and at the same time causing the Forbush decrease beginning at almost the same time, reaching maximum depression of about 4 to 5 percent during late June 5 and early June 6, and gradually recovering to normal as observed by the neutron monitor at Deep River [Natl. Bur. Standards, U.S., 1960].

Explorer VII data showed a slight increase in intensity to N^*_{112} = 18 counts/sec, at 1021 U.T. on June 1 from a normal value at 0839 U.T. on the previous pass. Apparently then the solar protons began arriving in the vicinity of the earth sometime between 0839 U.T. and 1021 U.T. There was no significant polar cap absorption reported; also no significant intensity increase was observed by ground neutron monitors during this event. The highest value of N^{**}_{112} during the event was 51 counts/sec corresponding to a solar proton intensity of 5 $(cm^2\ sec)^{-1}$, at 1205 U.T. This was about 3.5 hours after the beginning of the flare, and 1.5 hours before the end of the flare. During the middle of June 2, N^{**}_{112} was 22 counts/sec, corresponding to a solar proton intensity of about 1 $(cm^2\ sec)^{-1}$. By 1120 U.T. on June 3, N^{**}_{112} had returned to its normal value.

The flare-associated solar plasma ejected from the sun reached the earth and caused the storm sudden commencement and almost simultaneously caused the Forbush decrease observed by the neutron monitor. Presumably the plasma cloud also provides a mechanism for the enhanced solar proton intensity observed on June 4 by Explorer VII as there were no flares of importance greater than 1^+ observed June 3 or 4. During June 5, N^{**}_{112} was normal while the ground neutron monitor showed a Forbush decrease. The reason that N^{**}_{112} was normal may be that the slight proton intensity increase was compensated by the Forbush decrease of galactic cosmic rays. A Forbush decrease of about

20 percent during June 6 to June 9 returning to normal on June 10 was observed by Explorer VII, as well as by ground neutron monitors.

<u>August 12-16, 1960</u> (Figure 12).

On August 12, 1960 at 1924 U.T. a flare of importance 3^+ at the location N22E27 was observed at Hawaii observatory /Natl. Bur. Standards, U.S., 1960/. The flare ended at 2042 U.T. Explorer VII made only one pertinent set of observations, at about 1240 U.T. on August 12, N^{**}_{112} was 29 counts/sec, corresponding to a solar proton intensity of 2 $(cm^2\ sec)^{-1}$. From 0850 to 1220 U.T. on August 13 the intensity was 1.3 $(cm^2\ sec)^{-1}$; and on the following day, from 0820 to 1010 U.T., it was 0.8 $(cm^2\ sec)^{-1}$. On August 15, at about 1130 U.T., the excess intensity was slightly higher than 0.8 $(cm^2\ sec)^{-1}$. Instead of decreasing in intensity, a slight increasing of intensity was observed, which can be explained in a similar manner as the June 1-4 case, since here, too, a magnetic storm occurred with the onset at 1510 U.T. on August 14, almost coincident with the onset of a Forbush decrease observed by the neutron monitor at Deep River /Natl. Bur. Standards, 1960/. It was interesting to note that the flares observed for June 1-4 event and this event both occurred on the eastern part of the solar disk, and in both cases, the slight increase of intensity of solar protons observed after the storm sudden commencement. On August 16, N^{**}_{112} was about 15 percent to 20 percent above normal. On the following day N^{**}_{112} was back to the normal intensity.

<u>September 3-9, 1960</u> (Figures 13, 24, and 25).

This event is interesting for the remarkably long delay time in the arrival of solar protons in the vicinity of the earth, long rise time, and also long decay time.

A flare of importance 3^+ beginning at 0040 U.T. at N17E90 accompanied by Type IV radio emission is presumed to have been responsible for the emission of the observed particles. The flare ended at about 0154 U.T. Two passes of Explorer VII during early September 3, one at 0037 U.T., and the other one at 0221 U.T., showed no increase in intensity. There was no further data at high latitudes until 2322 U.T. At that time N^{**}_{112} was about 1000 counts/sec corresponding to 140 $(cm^2\ sec)^{-1}$ in omnidirectional intensity of protons with $E > 30$ MeV. From the Explorer VII data alone, the delay time, which is the time interval between flare and the detection of the first arrival of solar protons, was not known; however, the delay time can be estimated by looking at the onset of polar cap absorption. The beginning time of PCA was about 0500 U.T.

[Leinbach and Hartz, Private Communication, 1960], while 0400 U.T. was the onset time of the flare. Therefore the delay time can be estimated as about 4.5 hours.

The maximum intensity was observed by Explorer VII at 0155 U.T. and 0337 U.T. on September 4. N^{**}_{112} was about 1800 counts/sec, which corresponds to a solar proton flux of 250 $(cm^2\ sec)^{-1}$ with $E > 30$ MeV. From the entire time dependence of the solar proton intensity it is believed that the time at which the solar protons detectable by Explorer VII reached maximum intensity cannot be earlier than 0155 U.T. The rise time (the time of first arrival to the time at which the proton intensities reach maximum) for this event is estimated as not less than 20 hours. The Deep River neutron monitor data [Natl. Bur. Standards, U.S., 1960] indicate a rise time of much less than 5 hours, with a peak intensity at around 0830 U.T. on September 3. It is seen that there was a considerable time lag in reaching the vicinity of the earth between higher energy protons detectable by neutron monitor and the lower energy particles detectable by the 112 counters in Explorer VII. This result was consistent with the result reported by the Winckler group [Winckler, Bhavsar, Masley, and May, 1961] and the Goddard Space Flight Center group [Davis, Fichtel, Guss, and Ogilvie, 1961].

The time decay of the omnidirectional intensity can be expressed as a function of time measured in hours from the beginning time of the flare as $J_o = At^{-2.6}$ ($t > 25$ hrs). If t is measured from the time at which the proton intensity reached the maximum, then the decay cannot be expressed as a power law. The observed time duration of the solar protons in the vicinity of the earth was more than 5 days, which was more than ten times the observed time duration by ground neutron monitors.

The data from Explorer VII were received while the satellite was over North America and Australia. They differ in local time as well as hemisphere. Nevertheless, all the data were along the same intensity vs time curve, as shown in Figure 13. Apparently the solar protons for this event showed no impact zone effect, i.e., protons were isotropic. This result is consistent with that obtained by Wilson, Rose, and Wilson [1961]. During the event there were two storm sudden commencements at 0230 U.T. and 1145 U.T. on September 4. There was no significant increase of intensity of solar protons after the first SSC. No data are available for the period immediately following the second SSC. These two SSC's presumably were caused by solar plasma ejected at the time of the solar flares beginning at 0700 U.T. and 2230 U.T. on September 2. These two solar plasma clouds, which were between the sun and the earth at the time of September 3 solar flare, might be responsible for the observed long delay time discussed previously, as pointed out by Winckler et al. [1961]. Measurements of integral energy spectrum by Davis, Fitchel, Guss, and Ogilvie [see Winckler, Bhavsar, Masley, and May, 1961] revealed that the spectrum can be expressed as a power law of $E^{-1.1}$ for 20 MeV $< E <$ 210 MeV at 1730 U.T. on September 3. The proton intensity with $E >$ 135 MeV from the balloon measurements [Winckler, Bhavsar, Masley, and May, 1961] at 2400 U.T. on September 3 was 2.7 particles/cm^2 sec ster. At the same time, the omnidirectional intensity with $E >$ 30 MeV observed by Explorer VII was about 140 particles/cm^2 sec (Figure 13) corresponding to the directional intensity of 15 $\left(\frac{140}{3\pi}\right)$ particles/cm^2 sec ster. Combining the results of Explorer VII and the balloon observations at 2400 U.T. on September 3, yields the integral energy spectrum $E^{-1.17 \pm 0.03}$ for $30 < E < 135$ MeV. The results indicate that the energy spectrum did not change appreciably during 1730 U.T. to 2400 U.T. on September 3. However, for the higher energy range measured by the balloons, indications are that the spectrum is much steeper. During this event, solar α-particles were observed with an abundance of 3 to 7 percent of the solar protons of the same rigidity [Biswas, Freier, and Stein, 1962].

November 12-28, 1960 (Figures 14, 26, 27, and also 20).

Three solar proton events were observed in November 1960 by Explorer VII. The extensive studies on these events have been reported elsewhere, using the data from worldwide ground neutron and meson monitors [Steljes, Carmichael, and McCracken, 1961; Roederer, Manzano, Santochi, Nerurkar, Troncaso, Palmeira, and Schwachheim, 1961; Lockwood and Shea, 1961; Carmichael, Steljes, Rose, and Wilson, 1961; McCracken, 1962b]. The results from rocket observations on these events were reported by the NASA group [Ogilvie, Bryant, and Davis, 1962; Davis and Ogilvie, 1962].

The time history of the event as seen by the N^{**}_{112} during November 12 to November 30 is shown in Figure 14. The peak intensity observed by Explorer VII occurred around 2330 U.T. on November 12. Comparing the time of the peak intensity observed by Explorer VII and that of the second peak at about 2000 U.T. on the same day observed by ground neutron monitors [Steljes et al., 1961] we conclude that there is a time difference of about 3.5 hours between them.

The flare which was responsible for the November 12 event has been identified to be the flare of importance 3^+ at N26W04, which started at 1325 U.T. and ended at 1922 U.T. on November 12. There were two flares, one on November 10 and the other on November 11. Thus the November 12 flare took place and generated solar cosmic rays before the plasma fronts from the two earlier flares had reached the earth. Steljes et al. [1961] have proposed a model for the interpretation of the Deep River neutron monitor data for this event. According to their model [see Steljes et al., 1961, p. 1373, Figure 7], the plasma cloud which was ejected from the flare of November 11, dragged out from the sun a "frozen in" magnetic field to form a magnetic bottle. Solar cosmic rays ejected from the November 12 flare were trapped in the magnetic bottle. Some of the particles leaking out of the magnetic bottle were responsible for the first slow rising in the intensity of the neutron monitor. The second enhancement started at about 1900 U.T. and reached the peak at about 1935 U.T. The second enhancement, according to their interpretation, was due to the solar protons trapped in the magnetic bottle which expanded and enveloped the earth at 1900 U.T.

The 3.5 hours difference between the second peak of the neutron monitor and the peak of Explorer VII may be reasonably explained by their model, which is essentially an extension of the idea of Cocconi, Greisen, Morrison, Gold, and Hayakawa [1958], by assuming that the lower energy protons were mainly trapped in the inner loops of the magnetic bottle. Thus 3.5 hours elapsed before the inner loops of the expanding magnetic bottle went past the earth and the increase in the low energy protons was seen.

The discussion above is based on the assertion that the time variation which is observed during late November 12 and early November 13 is not caused by the change of the geomagnetic cut off during this period. There is no direct evidence that the data points for the period are taken from the latitude independent portion of N_{112} vs L plots. However, the K_p index was 8^+ for late November 12 and 9^- for early November 13. According to Figure 28, the geomagnetic cut off for 30 MeV protons is around L = 3.5 earth radii or less. The L values for the first 5 points shown in Figure 14 are, in time order, 3.3, 4.2, 3.6, 3.5, and 4.6. Therefore it is believed that the measured points lie in or at least very close to the latitude independent portion. This implies that the observed time variation of solar proton intensity during the period is not due to the change of the geomagnetic cut off.

Because of the very high solar proton flux during the period of the November events, the apparent rate of the 112 detector observed at high latitude is very far below the saturation counting rate of the detector. For example, during 2323 U.T. to 2331 U.T. on November 12, an apparent counting rate of the 112 detector showed increases up to its saturation rate (360 counts/sec) as the satellite was going north over North America; afterward, it decreased to an apparent rate of less than 1.5 counts/sec at L = 3.6. According to Figure 1, the true counting rate corresponding to an apparent rate of less than 1.5 counts/sec should be at least 85,000 counts/sec which correspond to an omnidirectional intensity of solar protons 12,000 particles/(cm^2 sec) with $E \geq 30$ MeV. At such a low apparent rate, the true rate derived from it should be taken as the lower limit. To estimate the approximate upper limit, we have recourse to the 302 detector, which shows an apparent rate of 10,000 counts/sec giving an omnidirectional intensity of solar protons of 46,000 particles/(cm^2 sec). The crude estimate of the solar proton intensity with $E > 30$ MeV, according to the above discussion, is somewhere between 12,000 to 46,000 particles/cm^2 sec at about 2330 U.T. on November 12. The directional intensity of solar protons is obtained from the omnidirectional intensity divided by 3π. Thus Explorer VII, at about 2330 U.T., yields a proton intensity of 1,270 to 4,900 particles/cm^2 sec ster with $E > 30$ MeV. Combining the results obtained by NASA Rocket 1025 [Ogilvie et al., 1962], which was launched at 2332 U.T. on the same day, yields an integral energy spectrum $E^{-1.9 \pm 0.5}$ for 30 MeV $< E <$ 120 MeV and $E^{-1.0 \pm 0.3}$ for 1.8 MeV $< E <$ 30 MeV. A large error is included in the spectrum due mainly to the crude estimate of the intensity observed by the satellite.

The solar proton intensity associated with the November 12 solar flare has been plotted vs time in log-log scale. The time decay follows t^{-2} for $10 < t < 50$, where t is measured in hours from the beginning of the solar flare. Comparing this result with $t^{-2.3}$ from the neutron monitors at Deep River and Ellsworth [Roederer et al., 1961], we observe that the decay is fairly close between the two for this event. The solar protons, detected by Explorer VII during late November 15 to November 20, were presumed to be associated with a flare of importance 3^+ at N26W33 which started at 0207 U.T. on November 15. This event differed from that of November 12 in the rapid rise in the Deep River neutron monitor rate [Steljes, Carmichael, and McCracken, 1961]. They have interpreted that as a consequence of the presence of a fairly well-ordered system of magnetic field connecting the earth to the sun at the time of the flare. Since the earth was then inside the magnetic bottle associated with the previous event, the well-ordered field is considered to supply a mechanism for the rapid passage of solar particles from the sun to the earth. Anisotropies which were observed by means of the worldwide network of neutron monitors occurred immediately after the initial rise [McCracken, 1962b], but there is no data available from the satellite early in the event. Explorer VII provided data of this solar proton event from late November 15, which is shown in Figure 14. All the data by Explorer VII, therefore, are presumed to correspond to times after the establishment of isotropy.

The omnidirectional intensity of solar protons with $E > 30$ MeV around 2200 U.T. on November 15 was about 11,000 $(\text{cm}^2 \text{ sec})^{-1}$. The riometer data showed that the maximum flux of particles above 20 MeV occurred about 20 hours after the flare [Leinbach, private communication, 1962]. Therefore the solar proton intensity measured around 2200 U.T. by Explorer VII may well represent the maximum intensity of this event. The intensity decreases hereafter and follows approximately $t^{-3.4}$ for $20 < t < 100$, where t is again measured in hours from the beginning of the flare. The decay of this event is faster than that of t^{-2} of the November 12 event. It appears that the well-ordered field between the sun and the earth has a profound effect upon the propagation of solar particles.

The intensities measured by the satellite during this period agree with that of the NASA rocket measurements [Davis and Ogilvie, 1962] to within a factor of 2. The detailed energy spectra for this event were available early in the event from balloon equipment [Ney and Stein, 1961] and late in the event from the rockets [Davis and Ogilvie, 1962]. The intensity enhancement from late November 20 observed by Explorer VII has been identified to be associated with a flare which started at about 2055 U.T. on November 20 at a solar longitude some 120° W of the center of the solar disk

[Carmichael, Steljes, Rose, and Wilson, 1961; Covington and Harvey, 1961]. Explorer VII showed an intensity enhancement at about 2200 U.T. which is about an hour after the beginning of the solar flare. The maximum intensity observed by the satellite for this event was about 1,800 $(cm^2\ sec)^{-1}$ at about 0130 on November 2.

For geographic latitudes north of about 48° N at 1000 km altitude over the polar caps it is of interest to note the time integrated omnidirectional intensity:

$$\int_{12\ \mathrm{Nov.}}^{16\ \mathrm{Nov.}} J_o\, dt \sim 2 \times 10^9/cm^2 .$$

This result may be compared to the one-year integral of galactic cosmic ray intensity in the same position of space measured by Explorer VII:

$$\int_{\mathrm{one\ year}} (J_o)_{c.r.}\, dt = 6.3 \times 10^7/cm^2$$

and the one-year integral of galactic cosmic ray intensity in interplanetary space [Van Allen and Frank, 1959]:

$$\int_{\mathrm{one\ year}} (J_o)_{c.r.}\, dt = 5.7 \times 10^7/cm^2 .$$

A detailed listing of all observational data from Explorer VII, together with its exact ephemerides, is contained in State University of Iowa Report 61-16 although some correction has since been made.

Part II

ENTRY OF NON-RELATIVISTIC SOLAR PROTONS INTO THE GEOMAGNETIC FIELD

1. Introduction.

Starting in 1904, Stormer and his students analyzed the problem of the motion of a charged particle in a dipole magnetic field [Stormer, 1955], and studied in detail the allowed and forbidden regions for entry. Compton [1933] pointed out that contours of constant intensity of cosmic rays correlated better with geomagnetic latitudes, derived from the dipole approximation of the earth's magnetic field, than with geographic. However, from an extensive study of the spatial distribution of cosmic ray intensities, Simpson, Fenton, Katzman, and Rose [1956] concluded that the geomagnetic coordinate system does not invariably provide the observed spatial distribution of cosmic ray intensities. Rothwell and Quenby [1958] demonstrated the existence of a close correlation between anomalies in cosmic ray intensity and those of the local magnetic field. Thereafter, Quenby and Webber [1959] computed numerically the vertical cut off rigidities using a sixth order field [Finch and Leaton, 1957] and demonstrated the excellent agreement between the observed cosmic ray equator and the contour of the maximum cut off rigidities.

2. Selection of a Coordinate System for Studying Latitude Dependence of Solar Proton Intensity.

To study the latitude dependence of solar proton intensity, it is necessary to organize the data through a proper choice of a parameter to represent the latitude. In the light of the discussion in the previous section, we first adopted Quenby and Webber's cut off rigidities as the suitable parameter. Solar proton intensities observed from Explorer VII, during May and November, 1960, were plotted as a function of this parameter. This leads us to the following conclusion: The observed solar proton intensity is not a single valued function of Quenby and Webber's cut off rigidities; in fact, the intensity is seen to vary rapidly along a contour of constant rigidity.

Since the solar protons arrive at high latitudes, probably guided by the lines of force, it appeared worthwhile to explore the use of a parameter such as L of McIlwain [1961], which characterizes the magnetic shell and is approximately constant along a line of force. The omnidirectional solar proton intensity J_o is plotted as a function of time but is actually a function of spatial position in Figure 15 and Figure 16, for two passes. These correspond to the periods 1836 U.T. to 1849 U.T. on May 4 and 1506 U.T. to 1518 U.T. on May 13, 1960. The figures also contained the parameter L as a function of time. L was computed for one minute intervals using the IBM 7070 computer of this University. From Figure 15 and Figure 16, we transform J_o as a function of L and these are shown in (b) of Figure 19 and (a) of Figure 23. In a similar manner, J_o vs L plots were derived for all the major solar proton events observed during 1960, and these are shown in Figure 17 through Figure 27.

The most valuable data for checking the adequacy of L as the parameter for the study of the spatial distribution of solar proton intensities are those of (e) of Figure 17, (c) and (d) of Figure 18, (b) of Figure 19, (c) of Figure 22, and (a), (c), and (e) of Figure 23. In all these cases, the data covered a wide range of longitude and latitude and in addition, contained both north bound and south bound passes which are indicated by $\uparrow$ and $\downarrow$ respectively in the figures. It is seen from the figures that five out of the total eight J_o vs L plots show exactly or almost exactly the same intensity at the same L of north bound and south bound passes. The differences in L of north bound and south bound passes are not greater than 0.2 earth radii. Although the J_o vs L plots do not coincide, nevertheless, the slopes for the L dependent part are almost equal.

The suitability of using L as a parameter for the study of the spatial distribution of the solar protons is further confirmed in Figure 19. Although each individual pass occurred at different longitudes, even more, at different hemispheres, nevertheless they show that the L dependent part of the intensity remain fairly constant during the geomagnetic quiet period of late May 4, 1960. All the J_o vs L plots from Northern Hemisphere and Southern Hemisphere fall very close to each other along a common line. The above observational results lead us to conclude that the L parameter indeed affords a reasonable means of organizing the data for the study of spatial distributions of solar protons at high latitudes.

It is seen that in most of the cases, the omnidirectional solar proton intensity for the latitude dependent part can be expressed as $\sim L^s$ $(s > 0)$. The value of s is fairly constant for one event, although no particular significance can be attached to the exponent at present. The value of s is 20 ± 2 on April 1, 10 ± 1.5 on April 28-29, 8.5 ± 1.0 on May 4-6, and 19 ± 2 on November 12, 1960.

3. Measurements of L_{min} and Correlations of L_{min} with K_p, U, and H.

It is seen in Figure 17 through Figure 27 that the solar proton intensity increases with increasing L up to certain value of L which is defined as L_{min}, then the intensity remains constant for $L > L_{min}$. Since in the major solar proton events observed during 1960 (except in April 1 event), the energy range of solar protons indeed extended below 30 MeV (as was discussed in Part I), we interpret the observed J_o vs L plots as follows: (1) The region of $L < L_{min}$ is forbidden for the entry of solar protons with energy less than 30 MeV. (2) The region of $L > L_{min}$ is completely open for the entry of solar protons with energy greater than 30 MeV. (3) The geomagnetic cut off energy at L_{min} should be 30 MeV corresponding to the rigidity of 0.239 BV, which is the threshold of the 112 detector carried in the satellite. (4) The variation of L_{min} is time variation; in other words, the variation of L_{min} is caused by the variation of the geomagnetic cut off with time.

The L_{min} together with their geographic positions observed during 1960 are tabulated in Table III. The table shows that L_{min} varies from 3.52 to 5.30 corresponding to the invariant latitude, 57.8 degrees to 64.3 degrees respectively, where the invariant latitude λ is defined by $\lambda = \text{arc cos } L^{-1/2}$. The differences in the λ between the maximum and minimum L_{min} are 6.5 degrees. The error in L_{min} due to uncertainty in reading from J_o vs L plots is estimated to be less than 0.2 earth radii, hence the difference of 1.78 between the observed maximum and minimum value of L_{min} cannot be due to this error. It is worthwhile to mention that Bhavsar [1961] estimated

TABLE III

MEASUREMENTS OF L_{min} DURING 1960 WITH EXPLORER VII

Time Duration of Satellite Pass (U. T.)		Time at L_{min} (U.T.)	Geographical Position of the Satellite at L_{min}			L_{min} Earth Radii
			Long.(deg)	Lat.(deg)	Alt.(Km)	
April 28	(1912-1921)	1915: 00	+129.7	-44.8	968.5	3.82
	(2059-2107)	2104: 00	+141.7	-50.4	851.4	5.05
	(2144-2152)	2146: 20	-81.4	+47.0	695.5	4.26
	(2326-2339)	2329: 00	-99.8	+48.7	716.7	4.10
		2337: 30	-55.7	+47.5	854.1	4.05
April 29	(0109-0122)	0111: 30	-118.8	+49.7	736.2	3.52
	(1854-1859)	1857: 55	+159.2	-50.4	893.3	4.36
	(2035-2044)	2042: 30	+151.2	-49.7	838.9	4.47
	(2123-2130)	2124: 00	-76.7	+48.0	694.5	4.56
		2128: 30	-52.9	+50.5	764.9	4.60
April 30	(0049-0057)	0050: 20	-107.3	+50.5	753.6	4.24
		0055: 45	-79.5	+47.2	841.3	4.40
May 4	(2025-2032)	2027: 30	+128.4	-49.7	916.8	5.30
May 5	(1817-1823)	1821: 35	+147.5	-50.3	952.1	4.90
	(2000-2007)	2005: 40	+136.2	-48.7	909.2	4.72
May 6	(1839-1845)	1841: 00	-76.1	+46.8	608.5	4.20
	(2021-2030)	2024: 00	-92.6	+48.9	626.8	4.40
May 7	(1729-1738)	1736: 00	+153.5	-50.0	966.7	4.50
	(1916-1921)	1918: 15	+133.4	-49.3	951.9	5.05
	(2000-2004)	2002: 10	-84.7	+49.9	632.1	4.95
	(2100-2104)	2101: 32	+117.1	-47.4	922.8	4.60
	(2143-2152)	2146: 00	-95.7	+50.3	663.5	4.70
		2148: 50	-80.5	+48.6	702.4	4.70
May 13	(1506-1518)	1510: 00	+127.6	-48.3	1082.9	4.89
		1514: 10	+147.6	-50.3	1056.7	5.00
	(1652-1701)	1658: 10	+135.8	-49.6	1031.0	5.14
	(1839-1843)	1841: 00	+117.9	-48.3	1013.5	4.95
Sept. 4	(0334-0338)	0337: 00	-94.2	+50.0	563.1	4.61
	(2254-2302)	2256: 00	+130.3	-45.8	1078.8	4.12
	(2345-2349)	2346: 30	-66.5	+44.4	578.8	3.65
Sept. 5	(0126-0129)	0127: 55	-91.2	+44.9	578.4	3.55
	(0225-0234)	0232: 15	+142.7	-44.7	1061.0	3.65
	(0310-0315)	0312: 00	-102.4	+48.8	566.5	3.95
Sept. 6	(0248-0252)	0249: 20	-97.1	+49.5	567.1	4.32
Nov. 22	(0017-0023)	0021: 20	+121.2	-47.9	715.1	4.62

from the neutron and gamma-ray-production by protons in the atmosphere that the protons with energy greater than 40 MeV are allowed to arrive at Minneapolis ($L = 3.26$) during the main phase of a magnetic storm, that is 40 MeV protons can go down to at least $L = 3.26$. Bhavsar's results indeed support our result that 30 MeV protons can reach down to at least $L = 3.53$ under certain conditions.

Since the variation of L_{min} is believed to be the variations in L at which the geomagnetic cut off energy is 30 MeV, it should be possible to find the quantitative dependence of L_{min} on some parameters which can describe the degree of geomagnetic disturbances. The dependence of L_{min} on K_p index is shown in Figure 28 and that on U and H are shown in Figure 29 and Figure 30, respectively, where U is the Kertz parameter [1958] which gives a measure of the equatorial ring current and H is the hourly mean of horizontal component of the geomagnetic field (at Tucson). It is seen that there are reasonable correlations. The correlation coefficient for L_{min} vs U is -0.88 and that of L_{min} vs H is +0.88. These correlations can be accepted with confidence since the data covered 25 observational points and were taken from the eight major solar proton events observed by Explorer VII during 1960.

The relation of I_{min} and U can be represented by the equation

$$I_{min} = 5.81 - 0.0134\ U$$

and that of I_{min} and H is

$$I_{min} = 2.62 + 0.015\ H.$$

The base value of the horizontal component at Tucson is taken arbitrarily to be 25,750 gammas. It should be mentioned that I_{min} does not correlate any better with the instantaneous horizontal component of the geomagnetic field observed at Tucson than with the hourly mean.

4. Discussion.

The result shown in Figure 29 indicates that $I_{min} = 4.7 - 5.3$ at U = 50 gammas. If we continue our discussion with the equation $I_{min} = 5.81 - 0.0134\ U$ then $I_{min} = 5.14$ at $U \approx 50$ gammas which is the value of U at a relatively geomagnetic quiet period. If the value U = 0 is taken to be the absolutely quiet period then $I_{min} = 5.81$ (extrapolated).

One can compare the measured value of I_{min} by the satellite and the theoretically calculated geomagnetic cut off. Difficulties might arise however, because the theoretically computed cut offs always refer to the vertical cut off at the ground whereas I_{min} is measured by an omnidirectional detector at the altitude range 550 km to 1100 km. Now at high L, the cut off rigidity is indeed a function of the direction of the incident protons, but the change in rigidity from the vertical is less than 15% at L = 3.5 and 10% at L = 5. In addition the vertical cut off along L in the altitude range of 0 to 1000 km is almost exactly the same [Sauer and Lin, private communication, 1963]. Therefore, according to the discussions above, the vertical cut off energy on the earth's surface at $L = L_{min}$ should be about 30 MeV as observed by the satellite. In Table IV, the observed L_{min} at U = 0, U = 50 gammas, and U = 170 gammas are shown together with the vertical cut off rigidities computed by Quenby and Wenk [1962] using a sixth order field.

The Quenby and Wenk vertical cut off rigidities are taken from Figure 31, in which the magnetic shell parameter L was computed and the vertical cut off rigidities were taken from the table of Quenby and Wenk [1962]. Values were taken for 2.5 degrees interval in latitudes and 5 degrees interval in longitudes for the region over Australia and that over North America as indicated in the same figure.

According to Table IV the observed cut off rigidity $R_{ob} = 0.239$ BV at L = 5.81 for U = 0 and the Quenby and Wenk cut off rigidity, $R_{qw} = 0.41$ to 0.47 BV at the same L.

TABLE IV

	R_{ob}, Observed Cut Off Rigidity in BV (Explorer VII)	R_{qw}, Computed Cut Off Rigidity in BV (Quenby and Wenk)	$\frac{R_{qw}}{R_{ob}}$
L = 3.54	0.239 (U = 170 γ)	1.15 to 1.25	~ 5
L = 5.14	0.239 (U = 50 γ)	0.53 to 0.60	~ 2.3
L = 5.81	0.239 (U = 0)	0.41 to 0.47	~ 1.8

This yields the ratio,

$$\frac{R_{qw}}{R_{ob}} \sim 1.8 ,$$

at L = 5.81. It is obvious that there exists a disagreement between the observed cut off and that of Quenby and Wenk. If we consider U = 50 gammas to be the value of U for a quiet period, then

$$\frac{R_{qw}}{R_{ob}} \sim 2.3 \quad \text{at} \quad L = 5.14 .$$

During a magnetically disturbed period of U = 170 gammas, $R_{qw}/R_{ob} \sim 5$.

The effect on reducing the geomagnetic cut off by the existence of westward ring current encircling the earth has been discussed by Ray [1956] using a filament type model ring current and by Kellogg and Winckler [1961] using a spherical shell type model ring current. If we assume that the observed reduction of the geomagnetic cut off is due to the effect of a ring current alone then the approximate magnetic moment of the ring current can be computed from the formula [Kellogg and Winckler, 1961]

$$R_{ob} = \frac{R_{qw}}{1 + \frac{M_R}{M_E}}$$

where M_R and M_E are the magnetic moments of the ring current and that of the earth respectively. According to the formula, it is required that $M_R = 0.8\ M_E$ for the absolute quiet period, that is to say, there exists a quiet ring current with $M_R = 0.8\ M_E$. For $U = 50\ \gamma$ and $170\ \gamma$, $M_R = 1.3\ M_E$ and $4\ M_E$ are required in order to explain the observational cut offs. However Akasofu and Lin [1963] showed that it is unlikely to be true that there exists a ring current with $M_R > M_E$ because of the limitation in the particle number density in the model ring current belt. Recent satellite observations (Explorer XII) showed that the geomagnetic field is confined within an approximate sphere with a radius of about 10 earth radii [Cahill and Amazeen, 1962]. Therefore it is believed that the observed anomaly in the cut off will be well explained by the combined effect of the ring current and the limitation of the geomagnetic field [Akasofu, Lin, and Van Allen, 1963, to be published].

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FIGURE CAPTIONS

Figure 1. Characteristic curves of apparent vs true counting rate (counts/sec) of Anton 112 Geiger counter.

Figure 2. Counting rates registered by 112 and 302 Geiger counters at the highest available latitudes during quiescent (non-solar event) times.

Figure 3. Counting rates registered over North America by 302 and 112 Geiger counters in Explorer VII on November 18,1959.

Figure 4. Counting rates registered over North America by 302 and 112 Geiger counters in Explorer VII on April 27-28, 1960.

Figure 5. Counting rates registered over North America by 302 and 112 Geiger counters in Explorer VII on April 28 (after the flare on April 28), 1960.

Figure 6. Counting rates registered over North America by 302 and 112 Geiger counters in Explorer VII on April 29, 1960.

Figure 7. Counting rates registered over North America by 302 and 112 Geiger counters in Explorer VII on April 30, 1960.

Figure 8. Time history of corrected rate of 112, N^{**}_{112}, during January 1-24, 1960.

Figure 9. Time history of corrected rate of 112, N^{**}_{112}, during March 23-April 15, 1960.

Figure 10. Time history of corrected rate of 112, N^{**}_{112}, during April 25-May 15, 1960 (PCA data, Leinbach, 1960).

FIGURE CAPTIONS (continued)

Figure 11. Time history of corrected rate of 112, N^{**}_{112}, during May 17–June 9, 1960.

Figure 12. Time history of corrected rate of 112, N^{**}_{112}, during August 2-August 25, 1960.

Figure 13. Time history of corrected rate of 112, N^{**}_{112}, during August 26–September 18, 1960.

Figure 14. Time history of corrected rate of 112, N^{**}_{112}, during November 12-November 30, 1960.

Figure 15. The omnidirectional solar proton intensity observed over Australia during 1836-1849, May 4, 1960.

Figure 16. The omnidirectional solar proton intensity observed over Australia during 1506-1518, May 13, 1960.

Figure 17. L dependence of the omnidirectional solar proton intensity observed during late April 28 to early April 29, 1960.

Figure 18. L dependence of the omnidirectional solar proton intensity observed during late April 29 to early April 30, 1960.

Figure 19. L dependence of the omnidirectional solar proton intensity observed on May 4, 1960.

Figure 20. L dependence of the omnidirectional solar proton intensity observed on May 5, May 6, and November 22, 1960.

FIGURE CAPTIONS (continued)

Figure 21. L dependence of the omnidirectional solar proton intensity observed during 1500 U.T.-1930 U.T., May 7, 1960.

Figure 22. L dependence of the omnidirectional solar proton intensity observed during 2000 U.T.-2200 U.T., May 7, 1960.

Figure 23. L dependence of the omnidirectional solar proton intensity observed on May 13, 1960.

Figure 24. L dependence of the omnidirectional solar proton intensity observed on September 3 and September 4, 1960.

Figure 25. L dependence of the omnidirectional solar proton intensity observed on September 5 and September 6, 1960.

Figure 26. L dependence of the omnidirectional solar proton intensity observed on November 12, 13, and 14, 1960.

Figure 27. L dependence of the omnidirectional solar proton intensity observed on November 15, 16, and 17, 1960; also on April 1, 1960.

Figure 28. Dependence of L_{min} on K_p.

Figure 29. Dependence of L_{min} on U.

Figure 30. Dependence of L_{min} on H.

Figure 31. Relation between R, Quenby and Wenk's cut off rigidity and L of McIlwain.

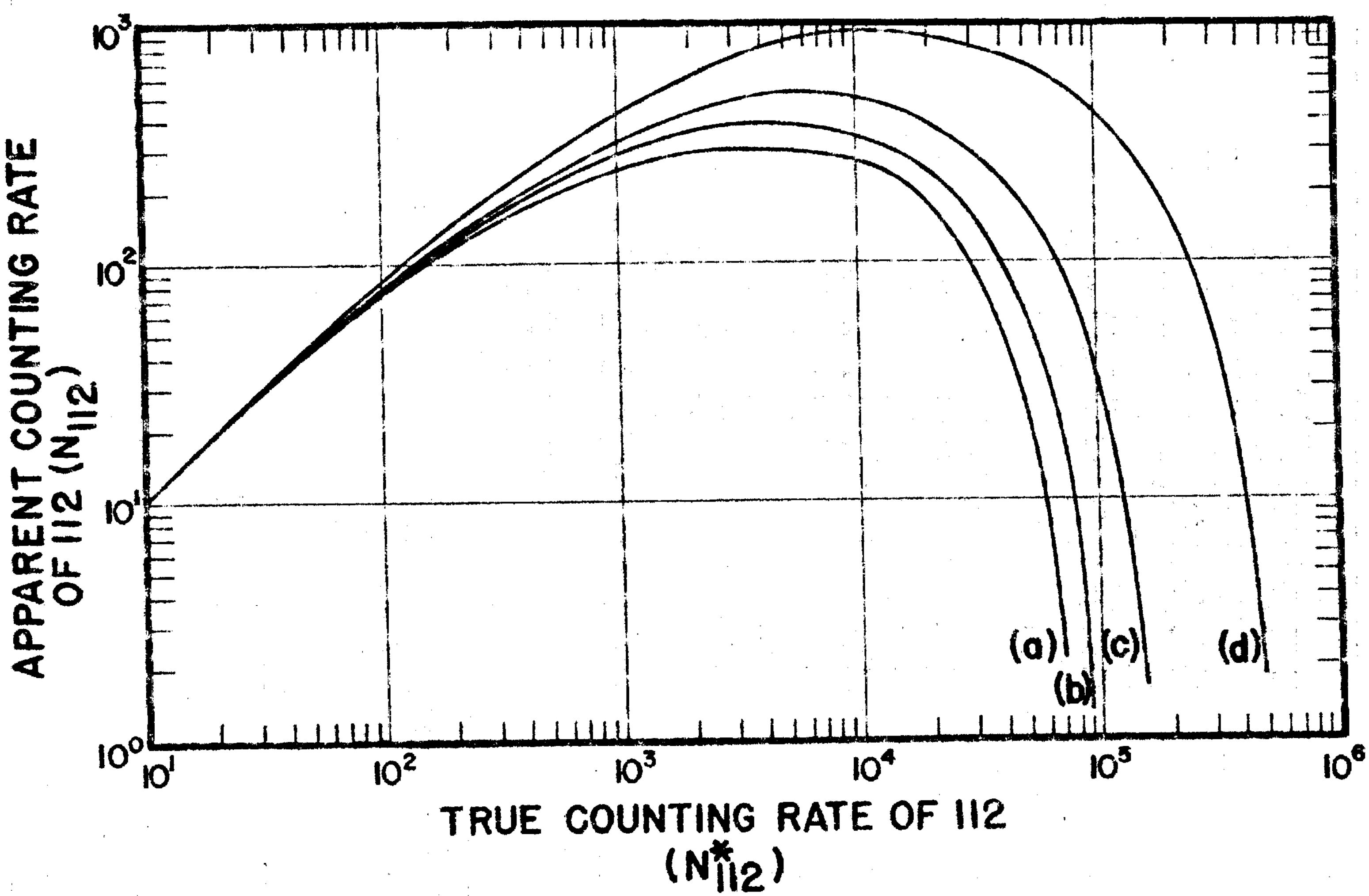
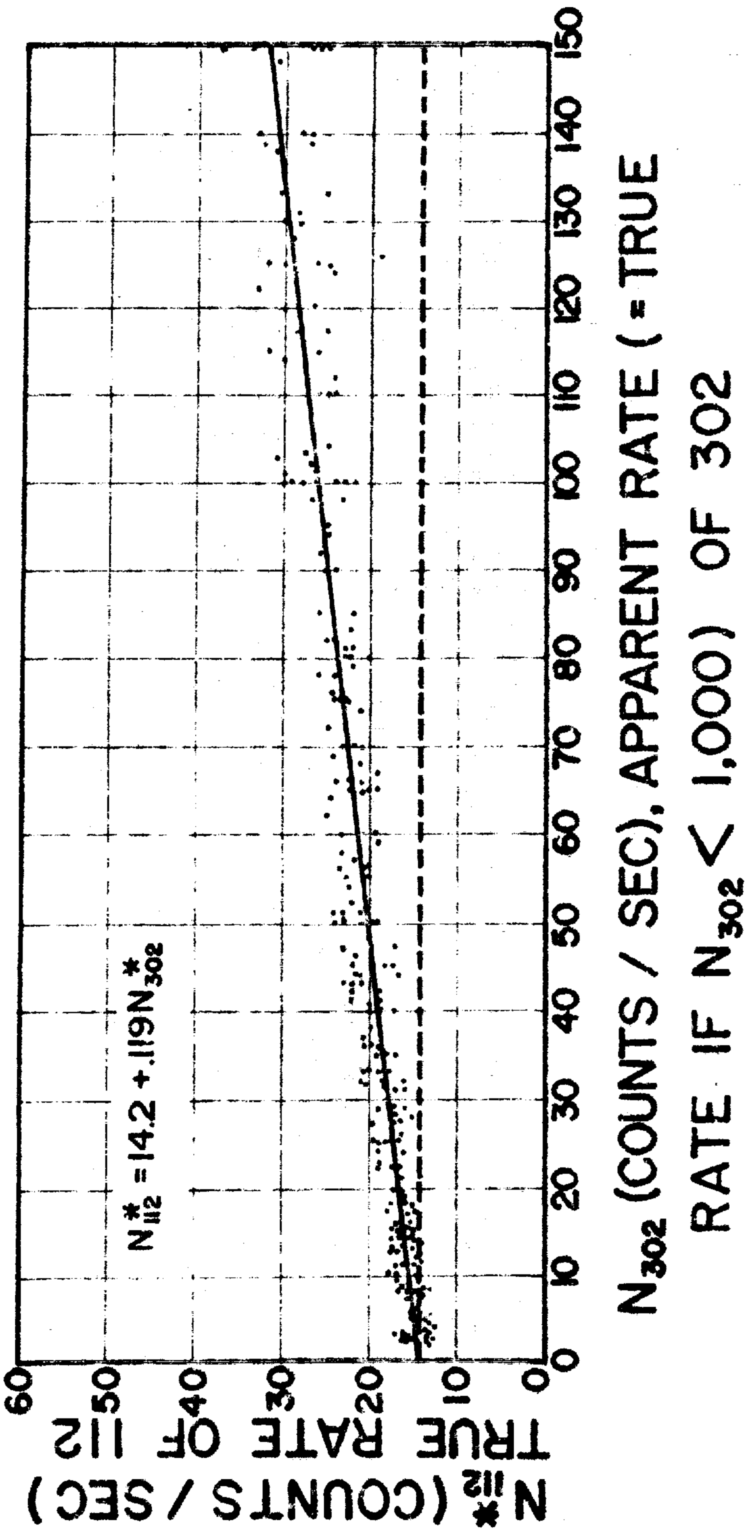

APPARENT COUNTING RATE
OF 112 (N_{112})
10^0
10^1
10^2
10^3
10^4
10^5
10^6
(a)
(b)
(c)
(d)
TRUE COUNTING RATE OF 112
(N^*_{112})

FIG. 1



N*112 = 14.2 + .119N*302
N302 (COUNTS / SEC), APPARENT RATE (= TRUE RATE IF N302 < 1,000) OF 302
N*112 (COUNTS / SEC) TRUE RATE OF 112
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

FIG. 2

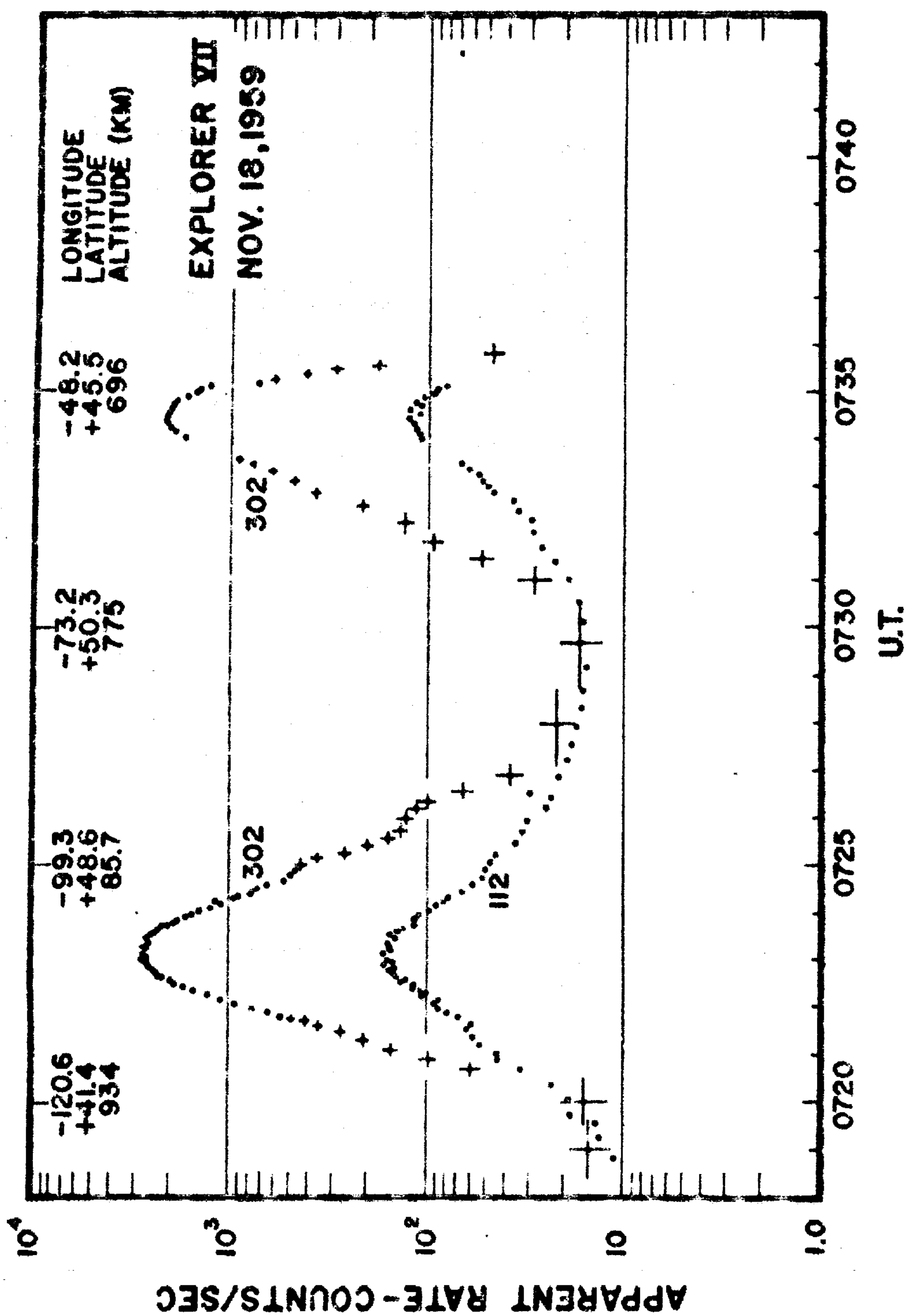

APPARENT RATE - COUNTS/SEC
10^4
10^3
10^2
10
1.0
0720
0725
0730
0735
0740
U.T.
-120.6
+41.4
934
-99.3
+48.6
857
-73.2
+50.3
775
-48.2
+45.5
696
LONGITUDE
LATITUDE
ALTITUDE (KM)
EXPLORER VII
NOV. 18, 1959
302
302
112

FIG. 3

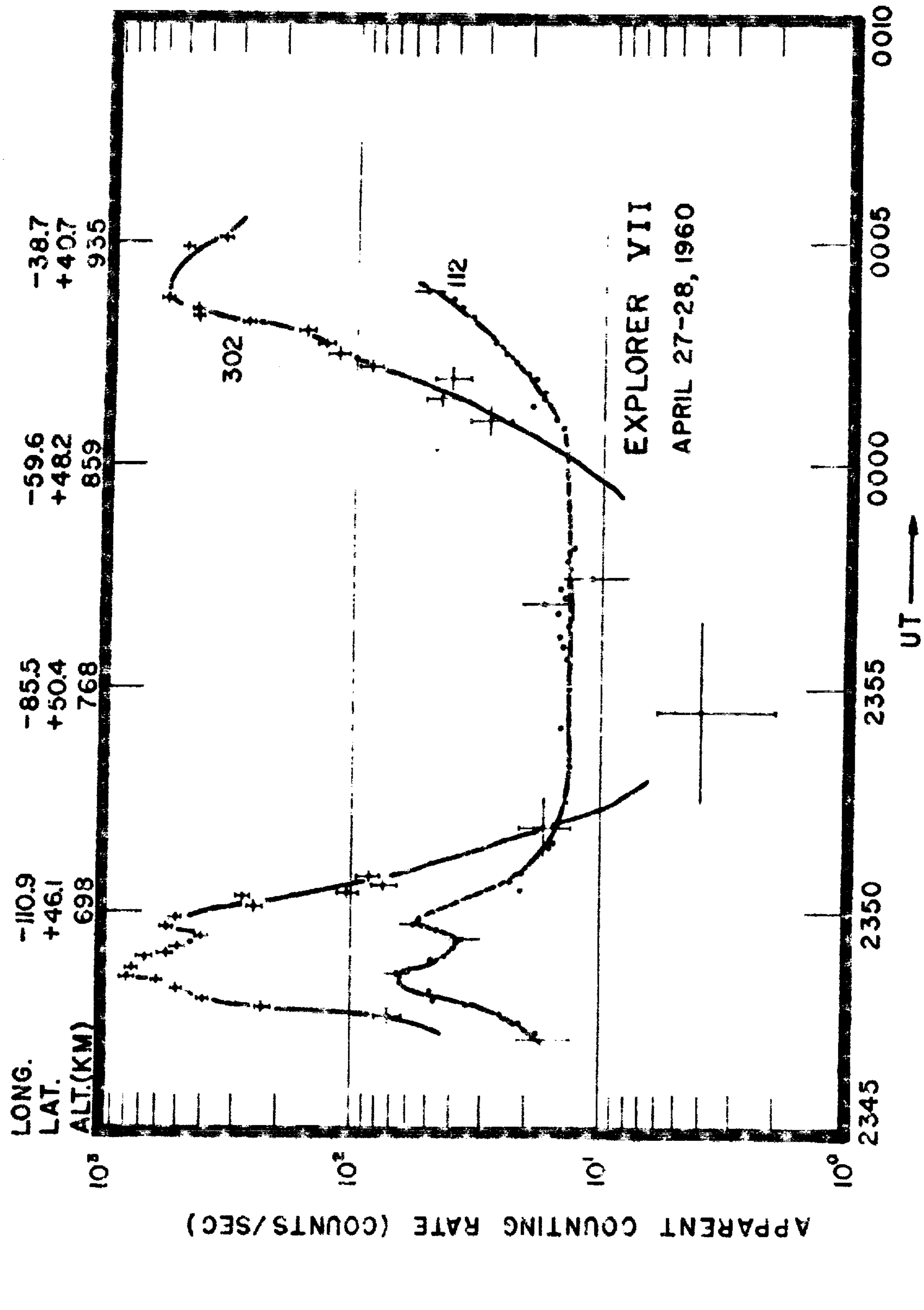
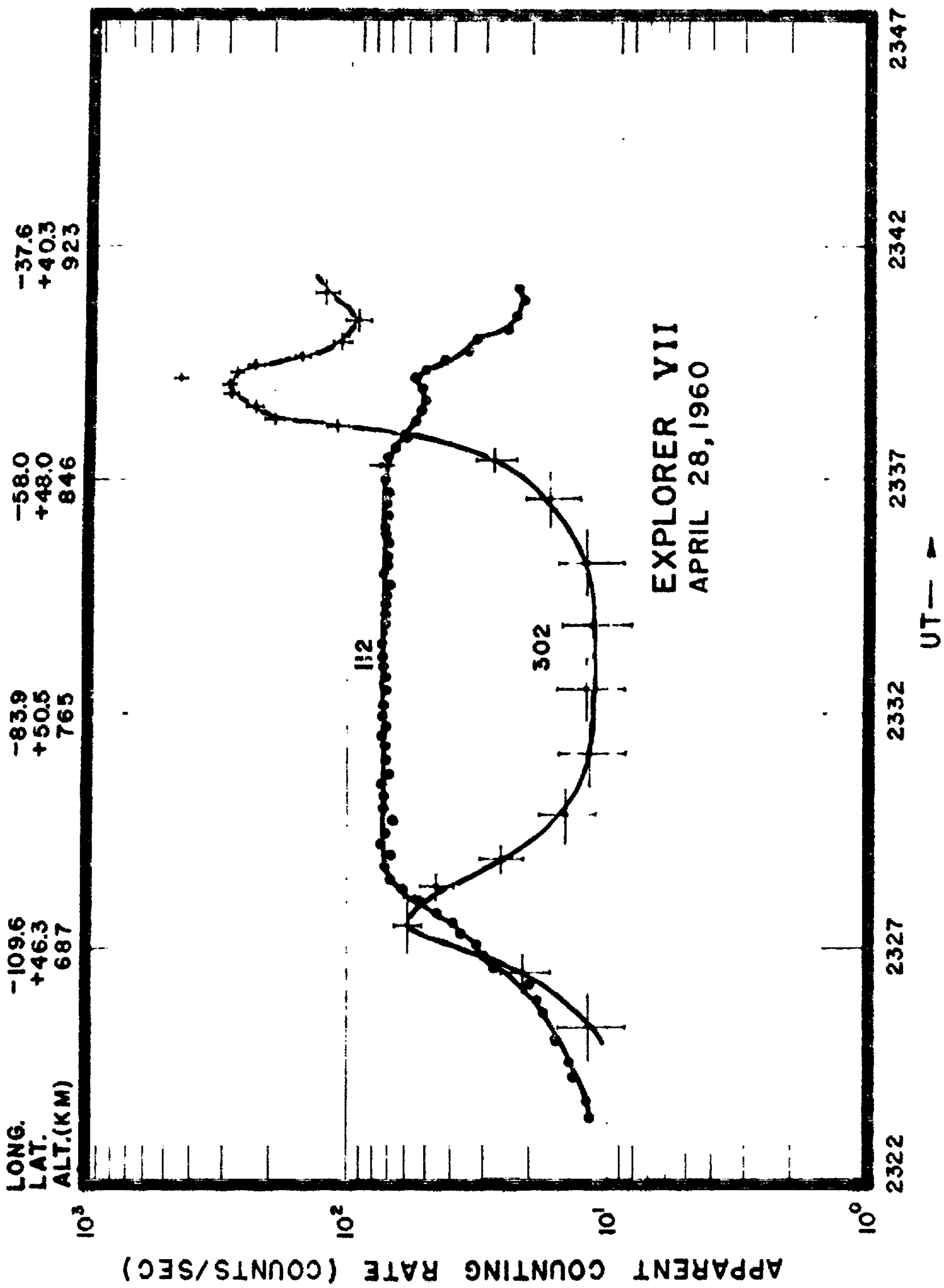
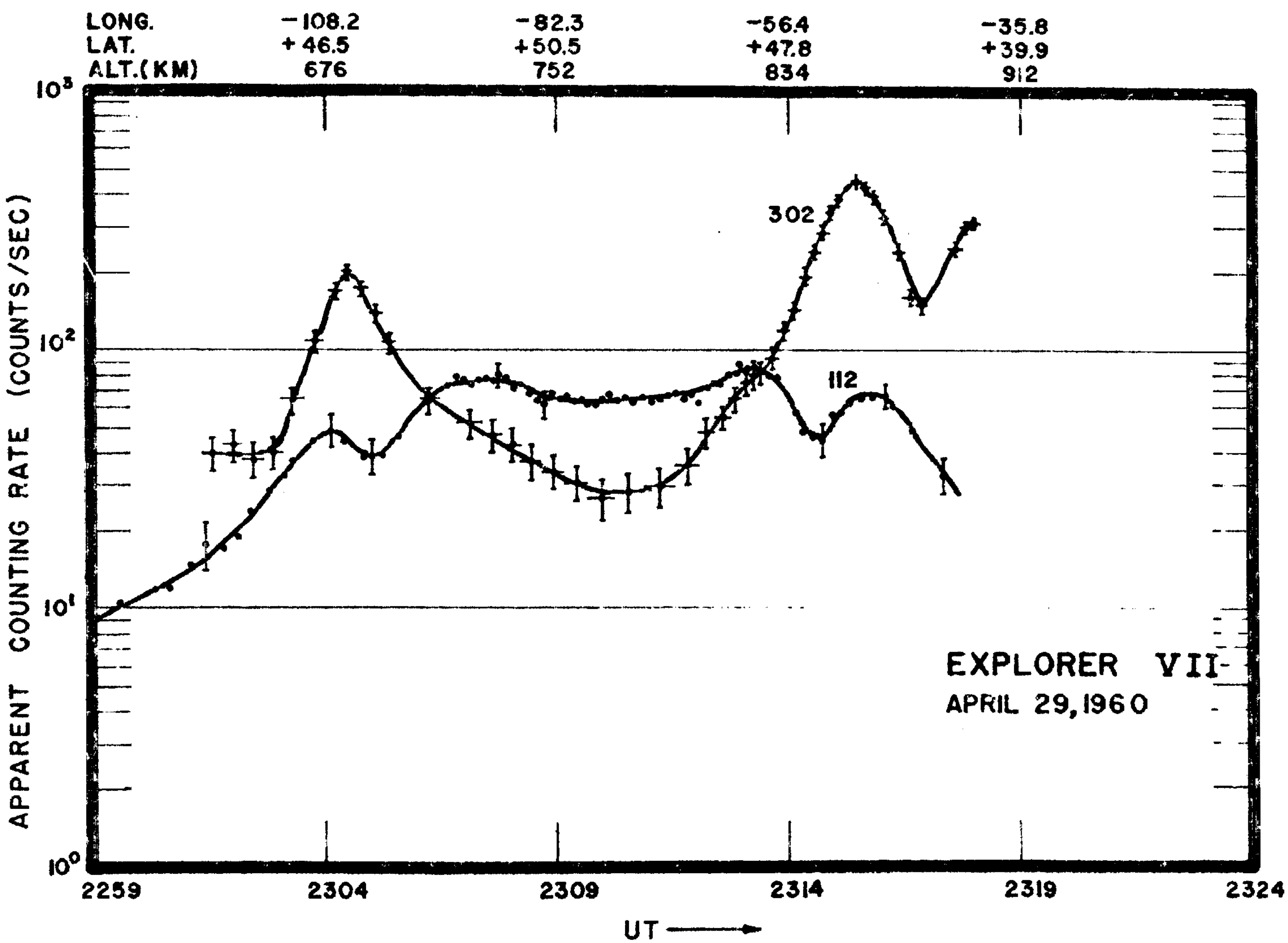

LONG.
LAT.
ALT.(KM)
-110.9
+46.1
698
-85.5
+50.4
768
-59.6
+48.2
859
-38.7
+40.7
935
302
112
EXPLORER VII
APRIL 27-28, 1960
2345
2350
2355
0000
0005
0010
UT
10^3
10^2
10^1
10^0
APPARENT COUNTING RATE (COUNTS/SEC)

FIG. 4



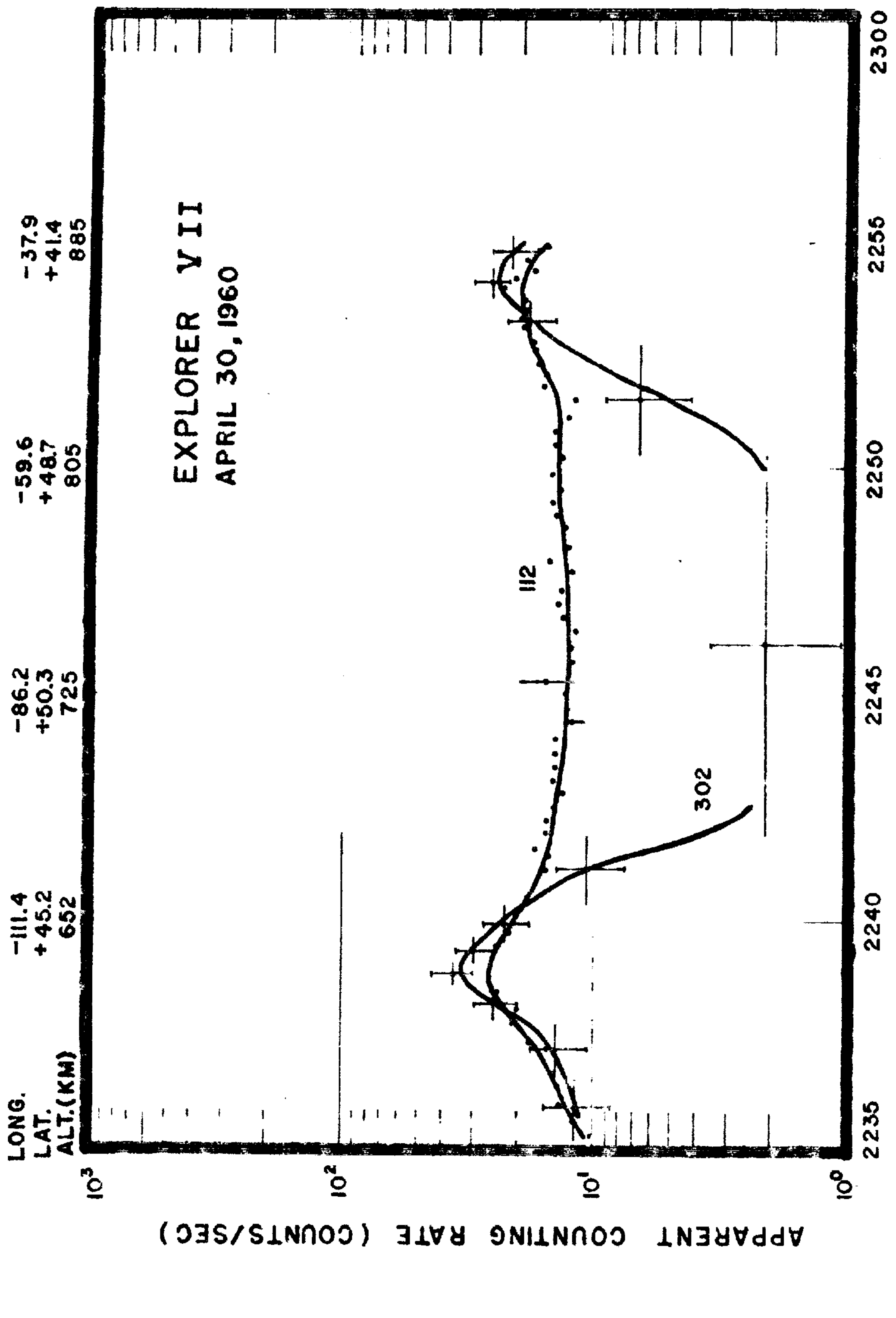
LONG.
LAT.
ALT.(KM)
-109.6
+46.3
687
-83.9
+50.5
765
-58.0
+48.0
846
-37.6
+40.3
923
112
302
EXPLORER VII
APRIL 28, 1960
10^3
10^2
10^1
10^0
APPARENT COUNTING RATE (COUNTS/SEC)
2322
2327
2332
2337
2342
2347
UT

FIG. 5



LONG.
LAT.
ALT.(KM)
−108.2
+46.5
676
−82.3
+50.5
752
−56.4
+47.8
834
−35.8
+39.9
912
APPARENT COUNTING RATE (COUNTS/SEC)
10^3
10^2
10^1
10^0
302
112
EXPLORER VII
APRIL 29, 1960
2259
2304
2309
2314
2319
2324
UT

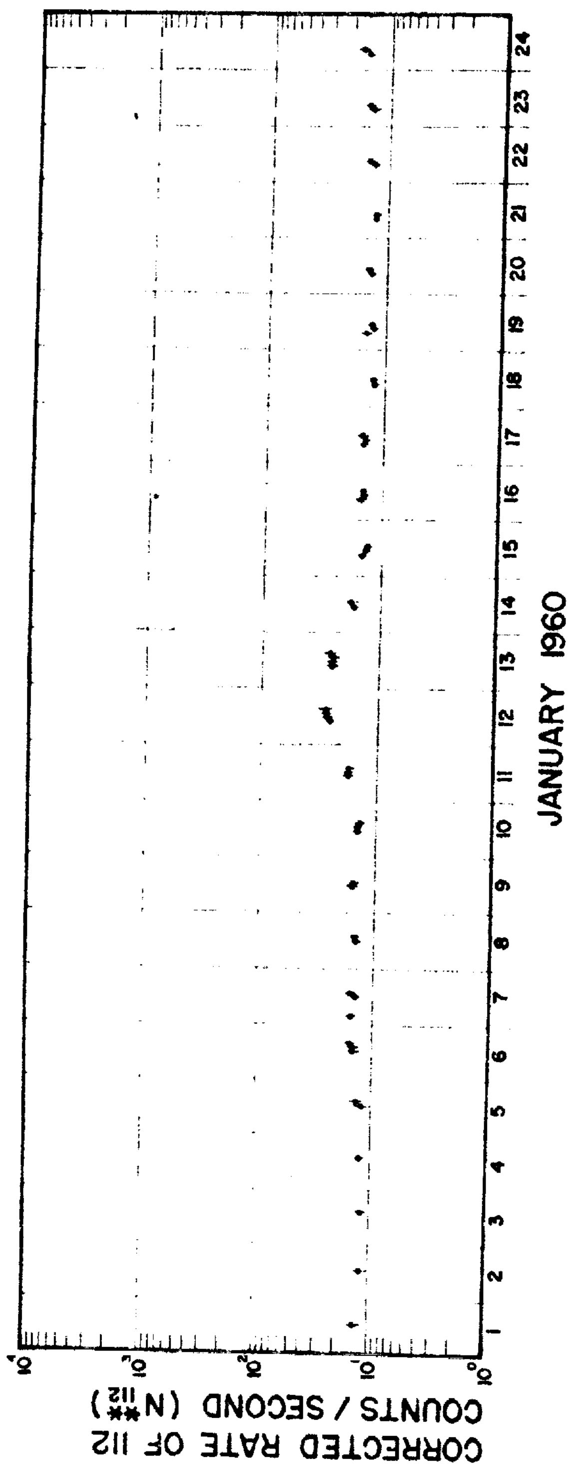
FIG. 6



EXPLORER VII
APRIL 30, 1960
LONG.
LAT.
ALT.(KM)
-111.4
+45.2
652
-86.2
+50.3
725
-59.6
+48.7
805
-37.9
+41.4
885
112
302
2235
2240
2245
2250
2255
2300
10^3
10^2
10^1
10^0
APPARENT COUNTING RATE (COUNTS/SEC)

UT ⟶

FIG. 7



CORRECTED RATE OF 112
COUNTS / SECOND (N**112)
10^4
10^3
10^2
10^1
10^0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
JANUARY 1960

FIG. 8

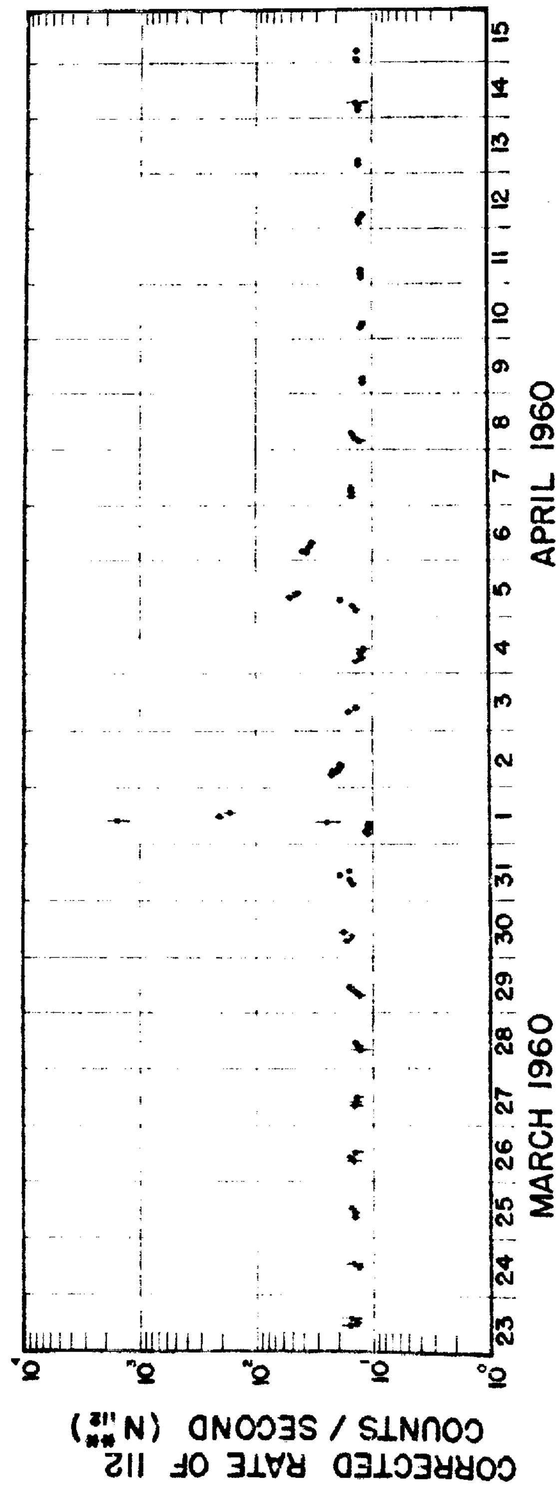
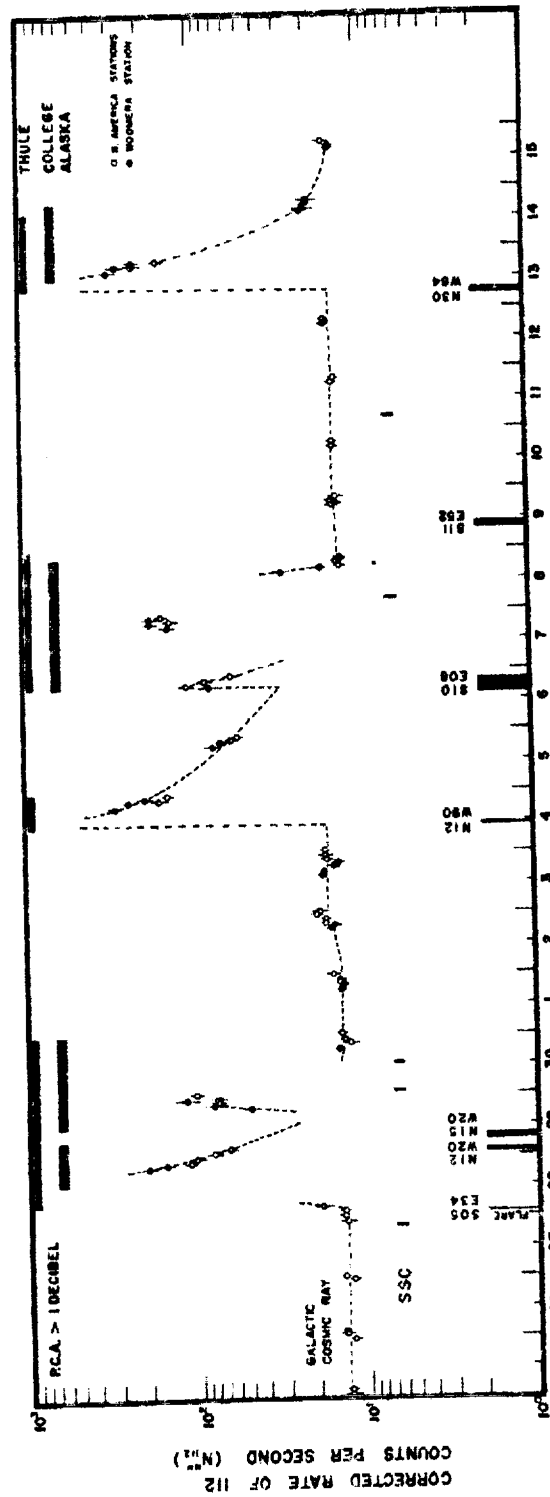

CORRECTED RATE OF 112
COUNTS / SECOND (N**112)
MARCH 1960
APRIL 1960

FIG. 9



P.C.A. > 1 DECIBEL
THULE
COLLEGE
ALASKA
GALACTIC COSMIC RAY
SSC
APRIL 1960
MAY 1960
CORRECTED RATE OF 112
COUNTS PER SECOND

FIG. 10

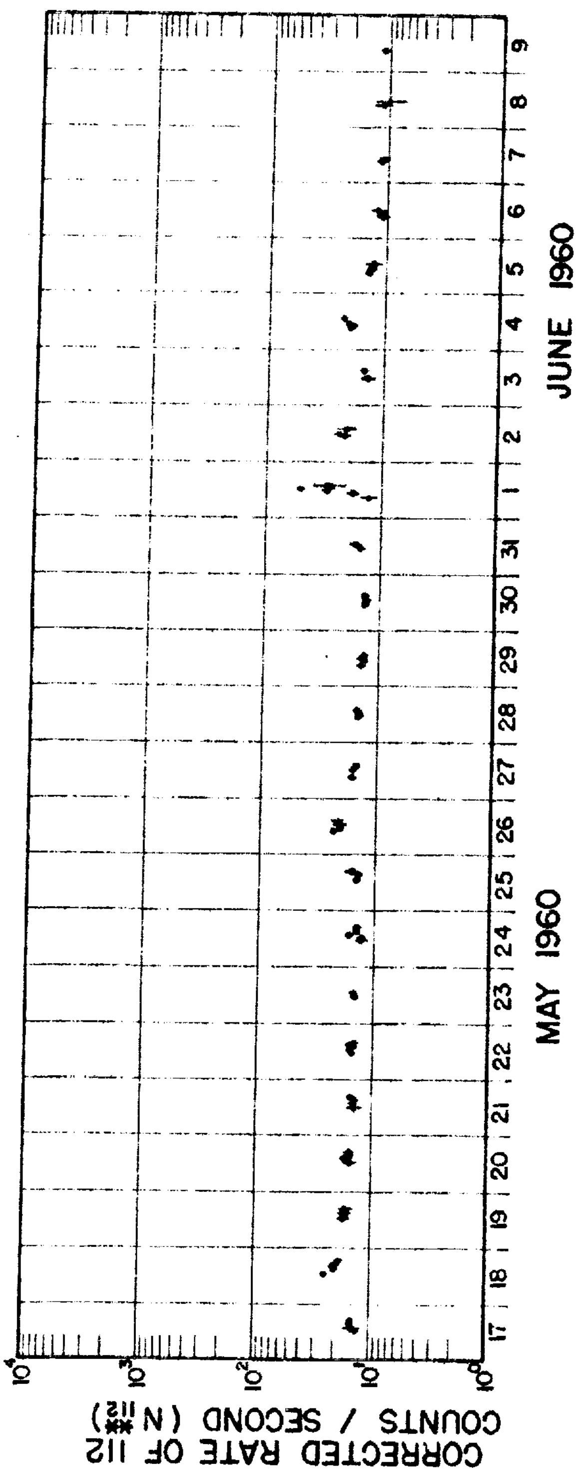


FIG. 11

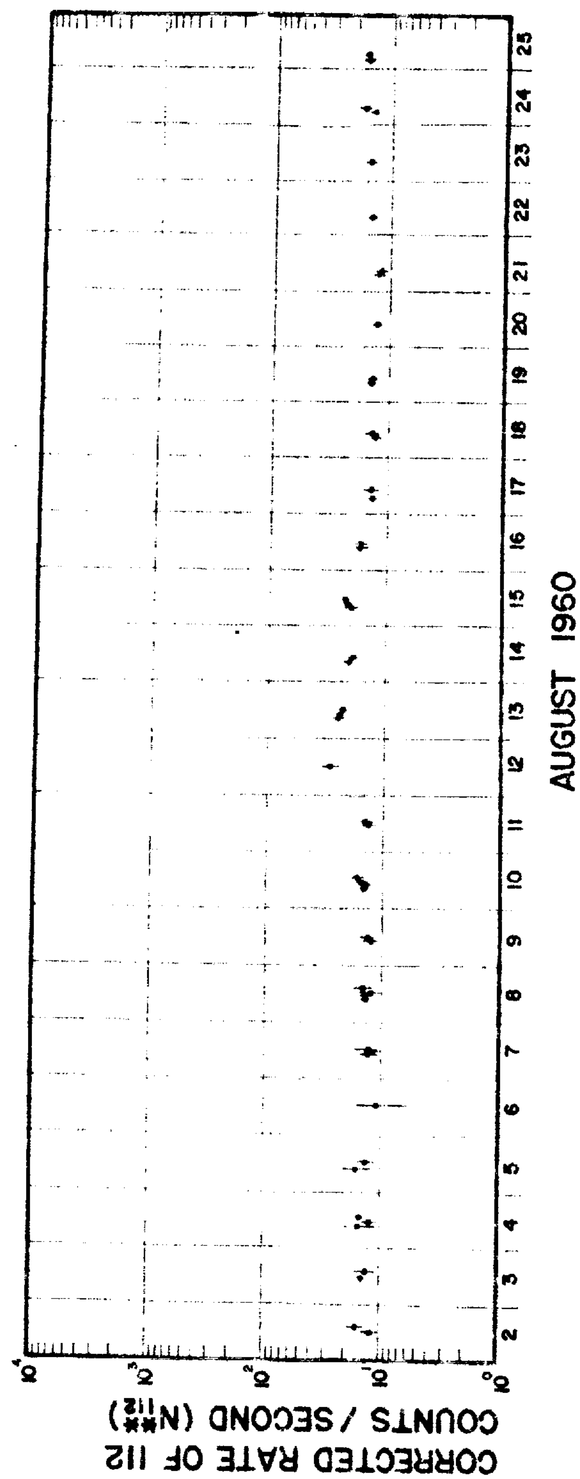
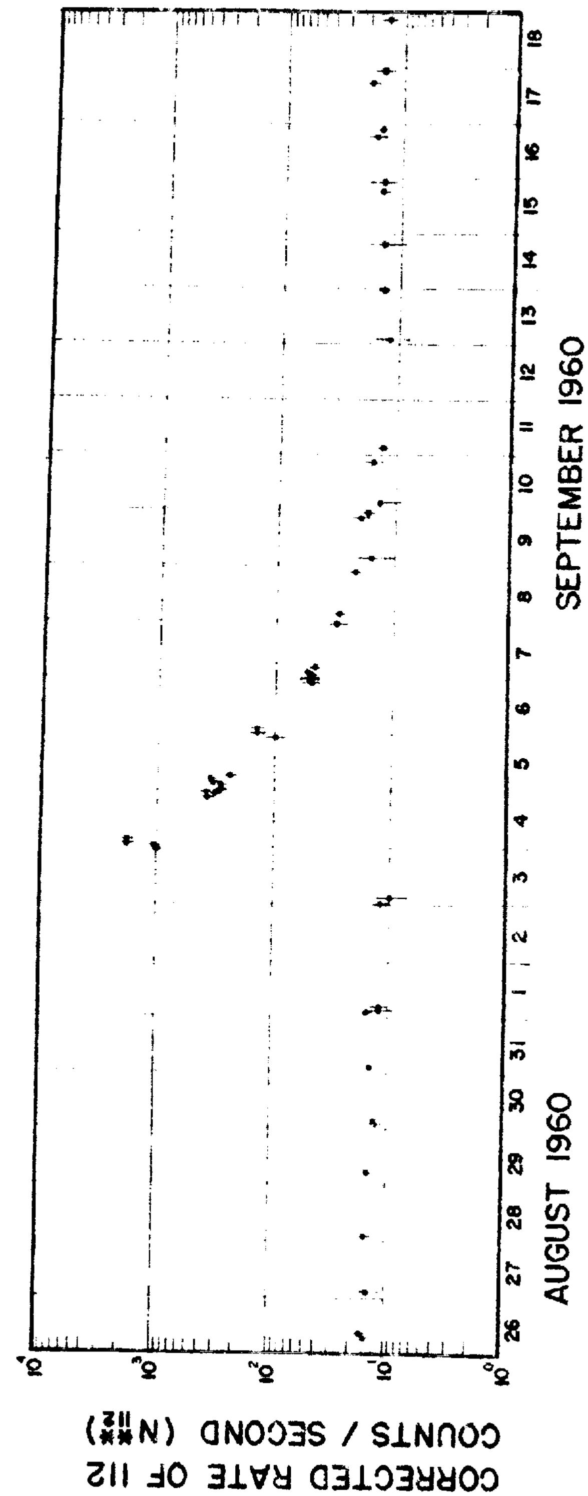


FIG. 12



AUGUST 1960
SEPTEMBER 1960
CORRECTED RATE OF 112
COUNTS / SECOND

FIG. 13

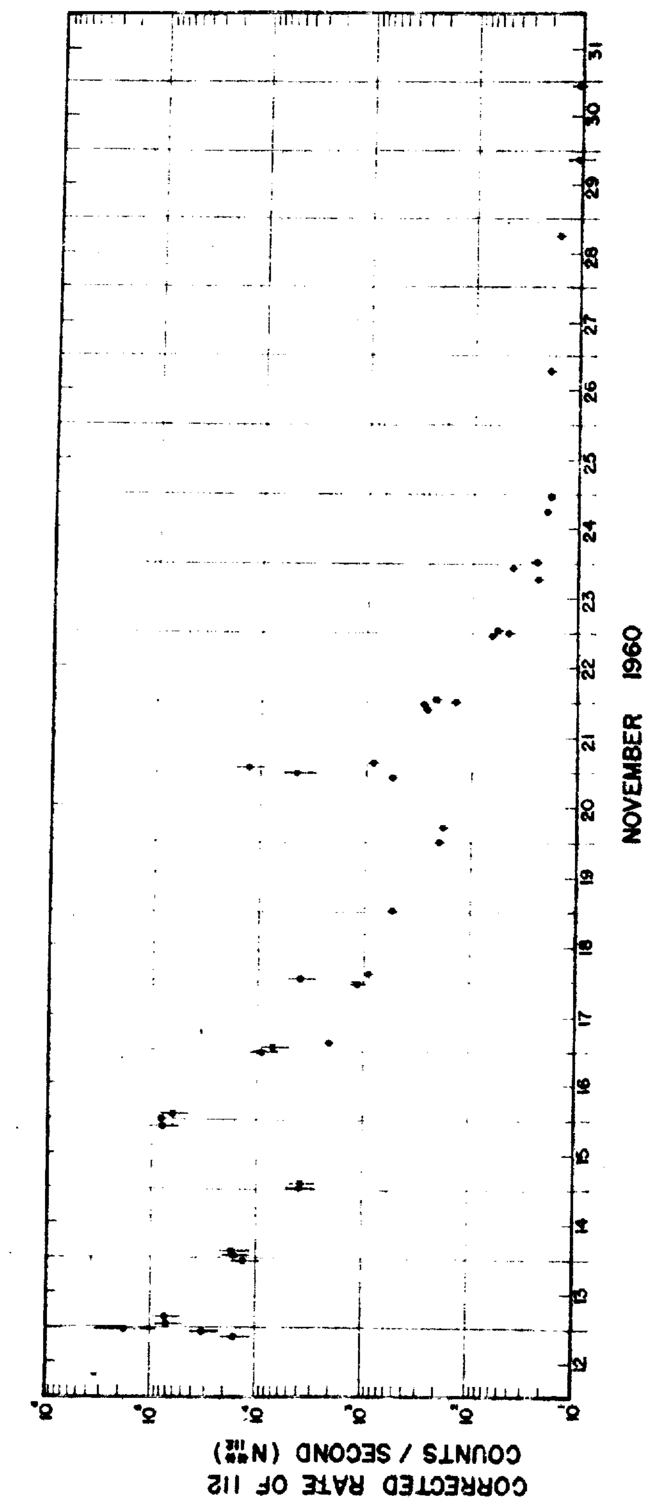


FIG. 14

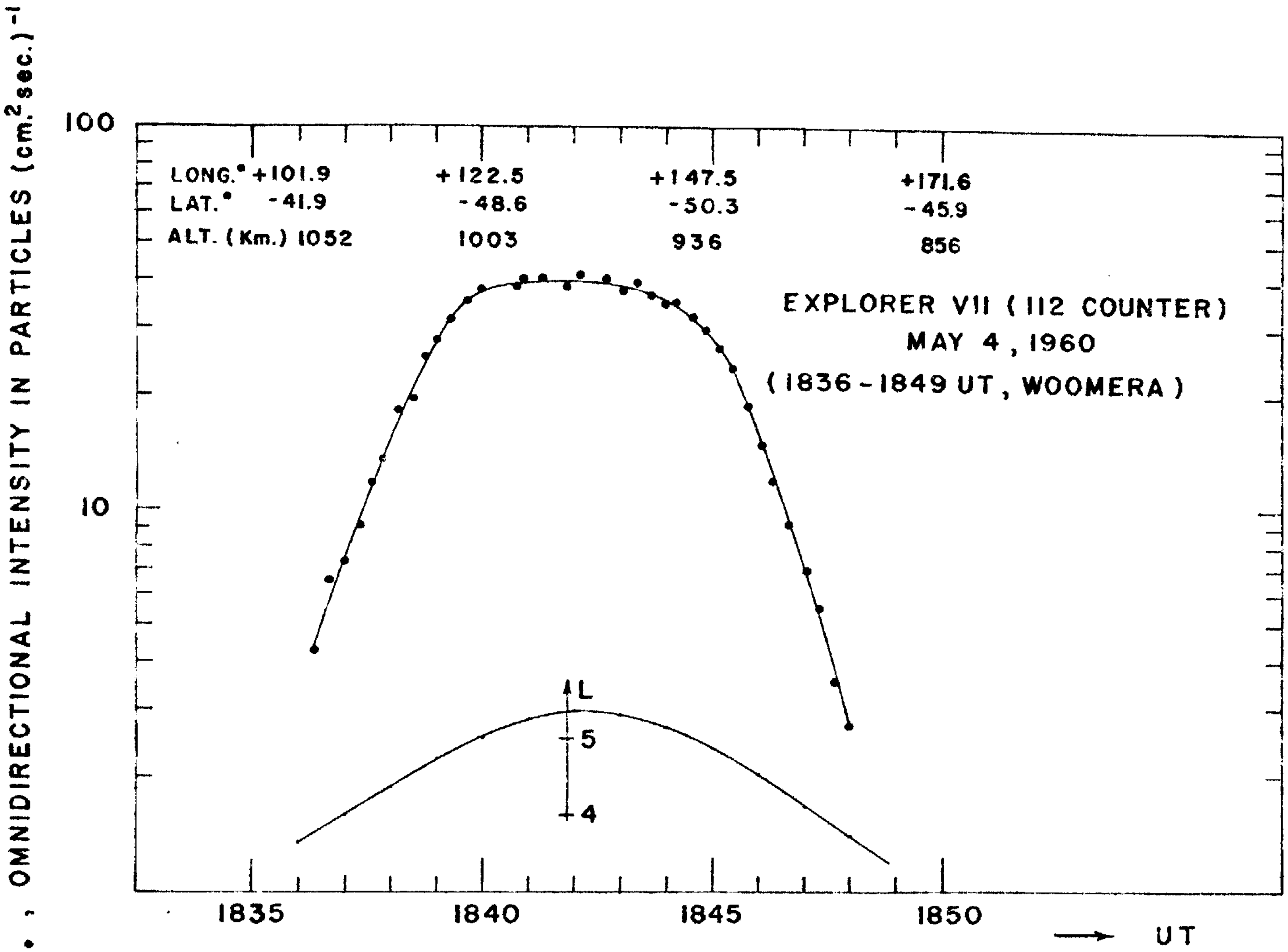

J₀ , OMNIDIRECTIONAL INTENSITY IN PARTICLES (cm.²sec.)⁻¹
100
10
LONG.° +101.9
LAT.° -41.9
ALT. (Km.) 1052
+122.5
-48.6
1003
+147.5
-50.3
936
+171.6
-45.9
856
EXPLORER VII (112 COUNTER)
MAY 4, 1960
(1836-1849 UT, WOOMERA)
L
5
4
1835
1840
1845
1850
UT

FIG. 15

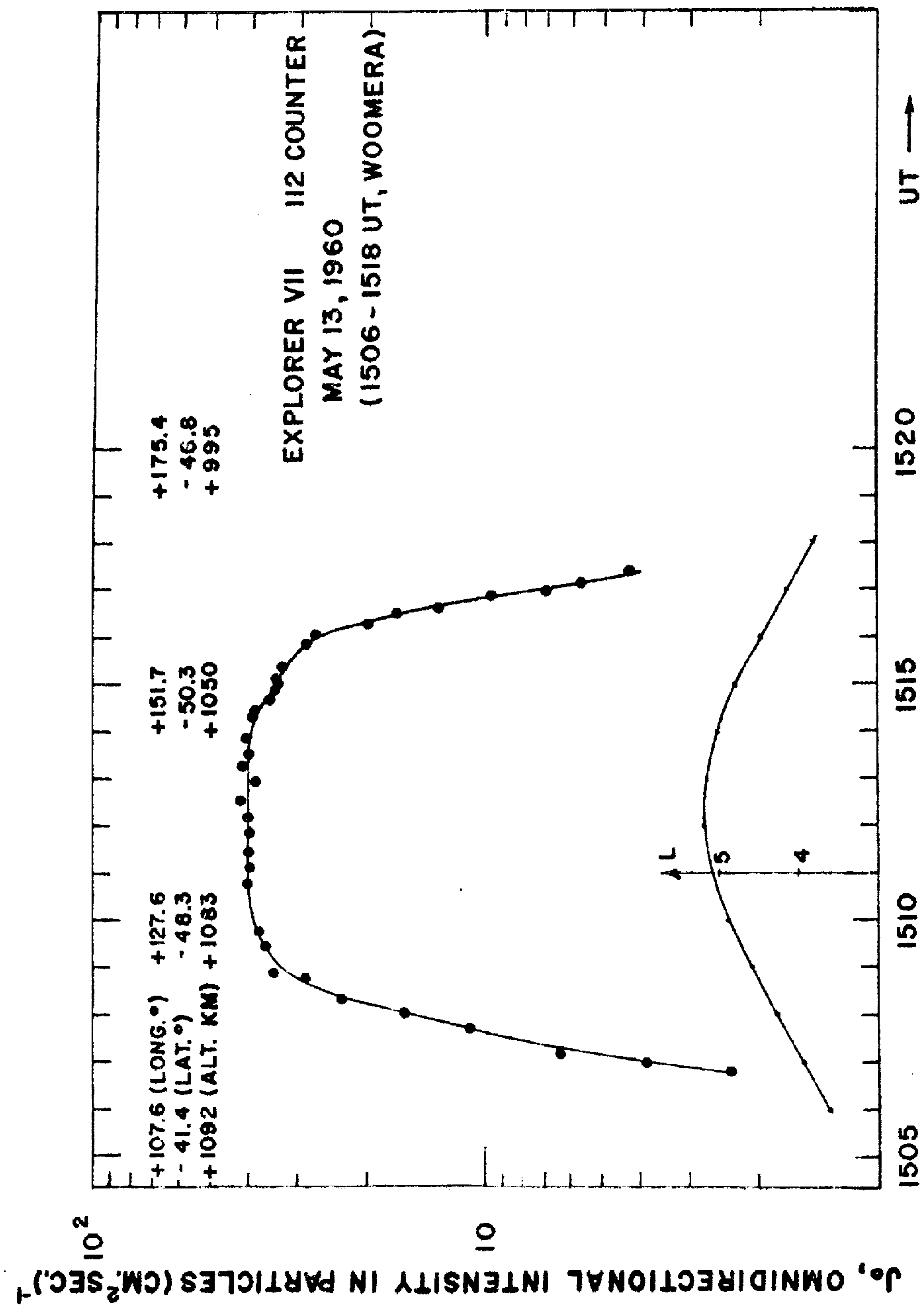

EXPLORER VII 112 COUNTER
MAY 13, 1960
(1506 - 1518 UT, WOOMERA)
+107.6 (LONG.°)
- 41.4 (LAT.°)
+1092 (ALT. KM)
+127.6
-48.3
+1083
+151.7
-50.3
+1050
+175.4
-46.8
+995
L
5
4
1505
1510
1515
1520
UT
10^2
10
J_o, OMNIDIRECTIONAL INTENSITY IN PARTICLES (CM^{2}SEC.)$^{-1}$

FIG. 16

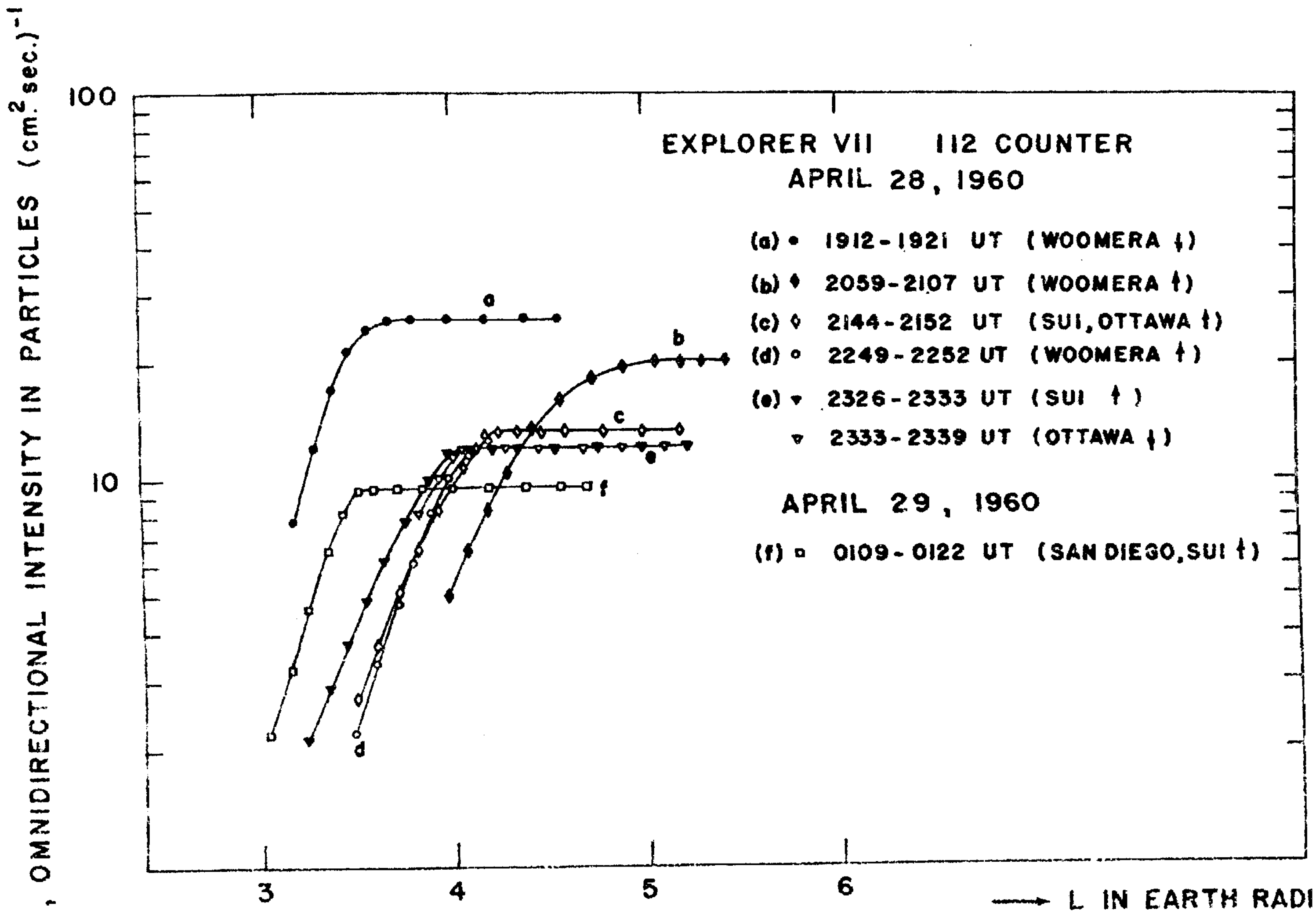

EXPLORER VII 112 COUNTER
APRIL 28, 1960
(a) • 1912-1921 UT (WOOMERA ↓)
(b) ♦ 2059-2107 UT (WOOMERA ↑)
(c) ◊ 2144-2152 UT (SUI, OTTAWA ↑)
(d) ○ 2249-2252 UT (WOOMERA ↑)
(e) ▼ 2326-2333 UT (SUI ↑)
▽ 2333-2339 UT (OTTAWA ↓)
APRIL 29, 1960
(f) □ 0109-0122 UT (SAN DIEGO, SUI ↑)
a
b
c
d
e
f
100
10
3
4
5
6
J$_0$, OMNIDIRECTIONAL INTENSITY IN PARTICLES (cm^2 sec.)$^{-1}$
→ L IN EARTH RADII

FIG. 17

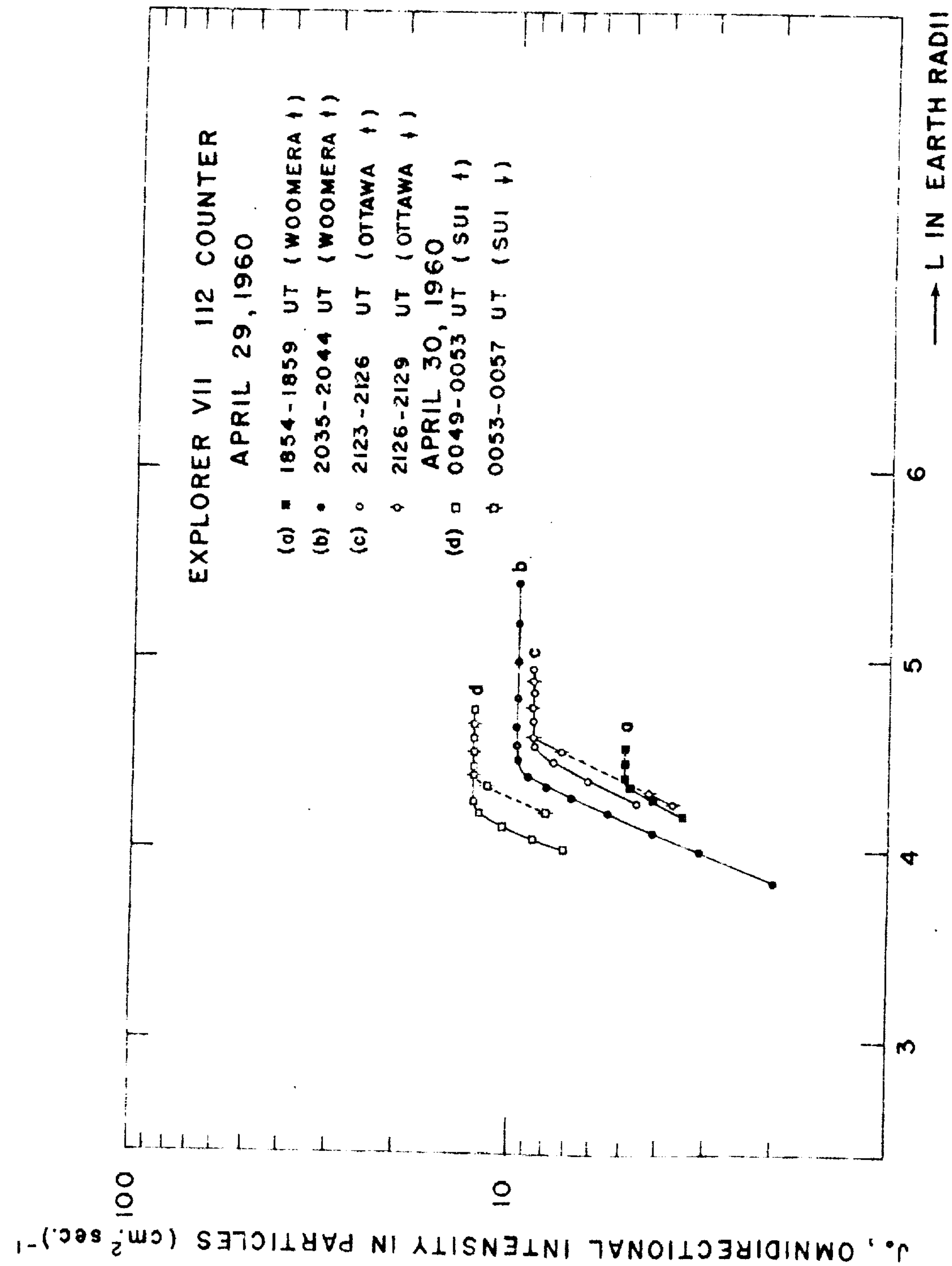

EXPLORER VII 112 COUNTER
APRIL 29, 1960
(a) ■ 1854-1859 UT (WOOMERA)
(b) ● 2035-2044 UT (WOOMERA)
(c) ○ 2123-2126 UT (OTTAWA)
◇ 2126-2129 UT (OTTAWA)
APRIL 30, 1960
(d) □ 0049-0053 UT (SUI)
◇ 0053-0057 UT (SUI)
a
b
c
d
3
4
5
6
→ L IN EARTH RADII
10
100
J., OMNIDIRECTIONAL INTENSITY IN PARTICLES (cm² sec.)⁻¹

FIG. 18

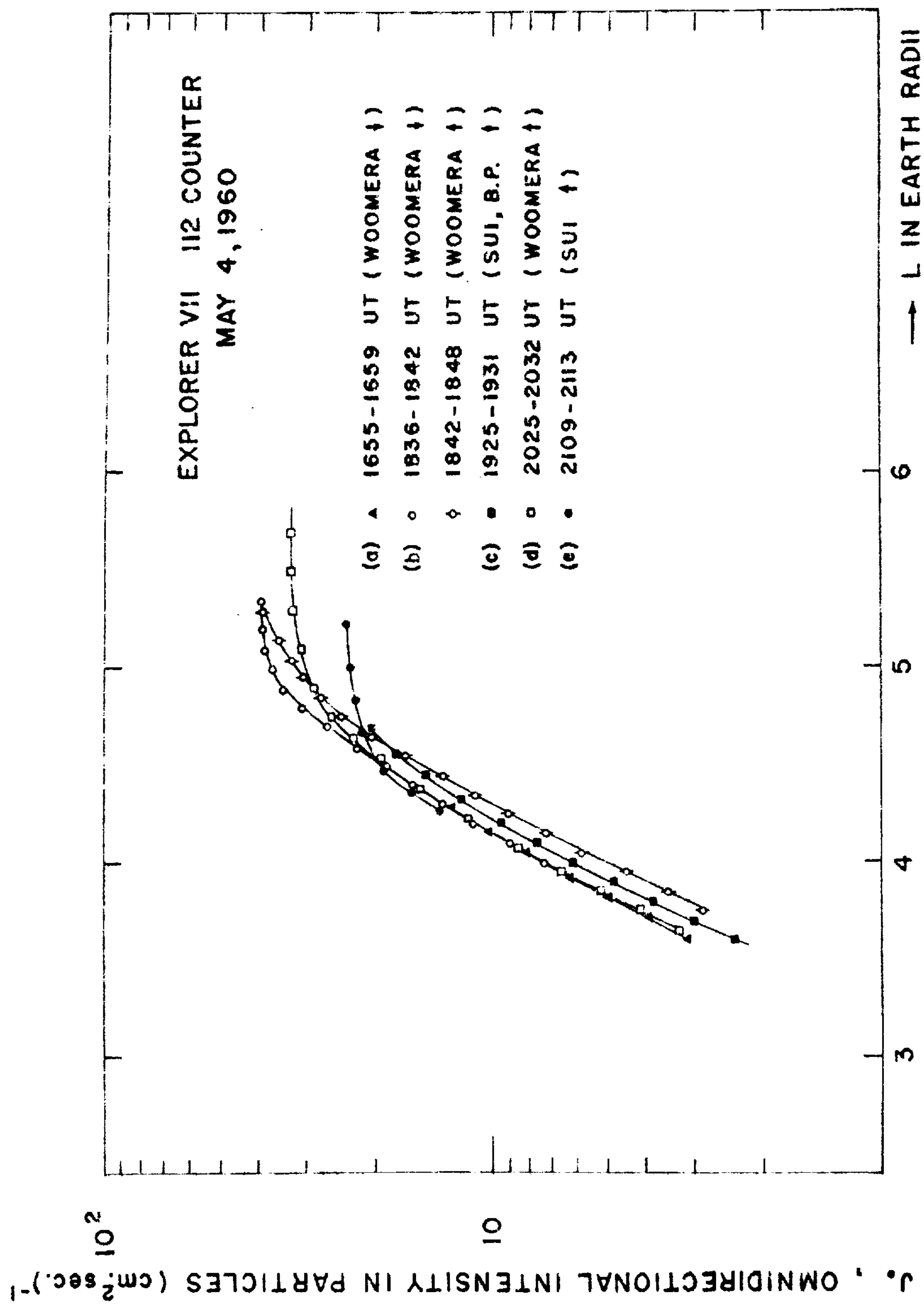

EXPLORER VII 112 COUNTER
MAY 4, 1960
(a) ▲ 1655-1659 UT (WOOMERA ↓)
(b) ○ 1836-1842 UT (WOOMERA ↓)
◇ 1842-1848 UT (WOOMERA ↑)
(c) ■ 1925-1931 UT (SUI, B.P. ↑)
(d) □ 2025-2032 UT (WOOMERA ↑)
(e) ● 2109-2113 UT (SUI ↑)
3
4
5
6
→ L IN EARTH RADII
10
10^2
J, OMNIDIRECTIONAL INTENSITY IN PARTICLES $(cm^2 sec.)^{-1}$

FIG. 19

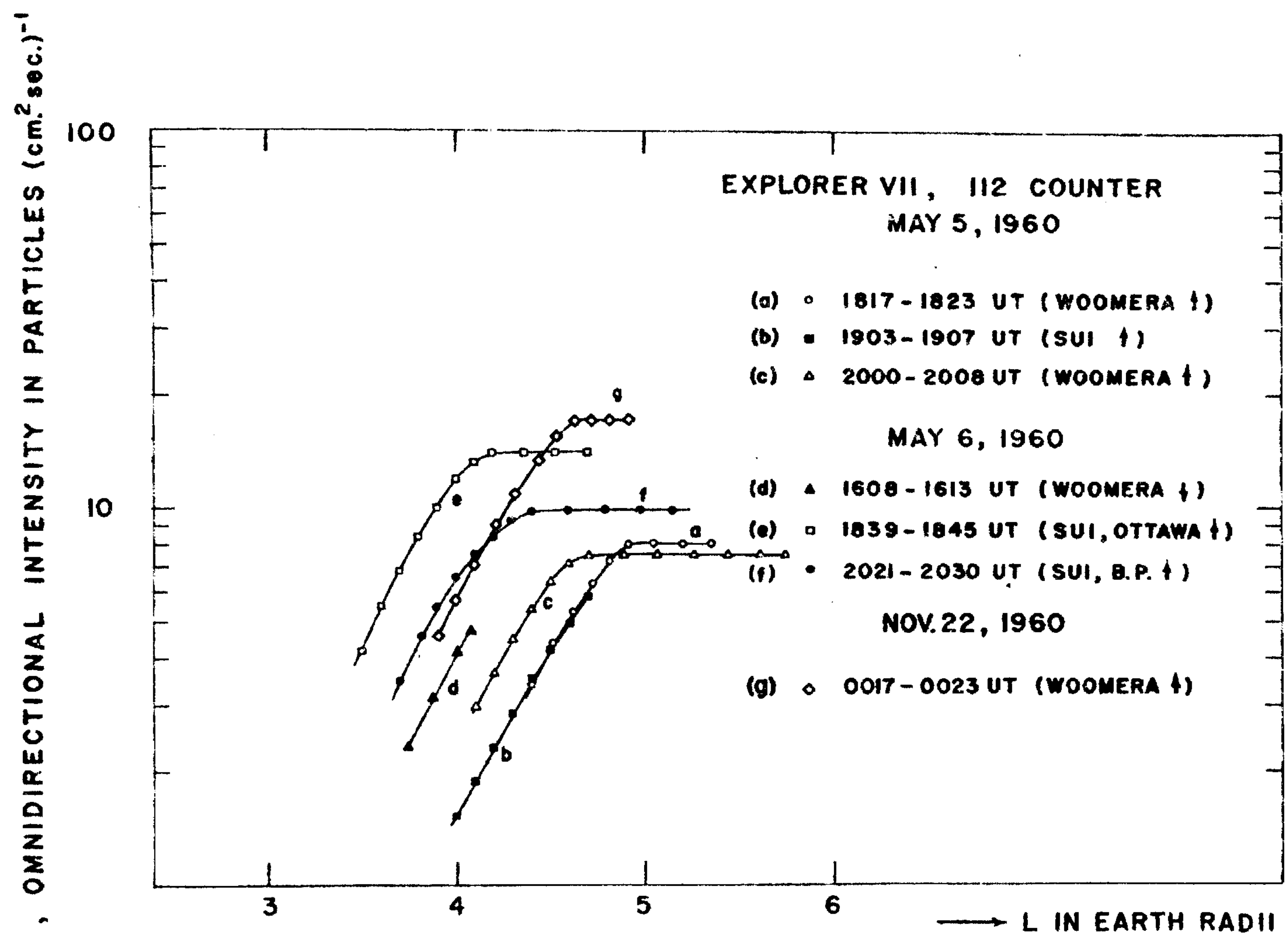
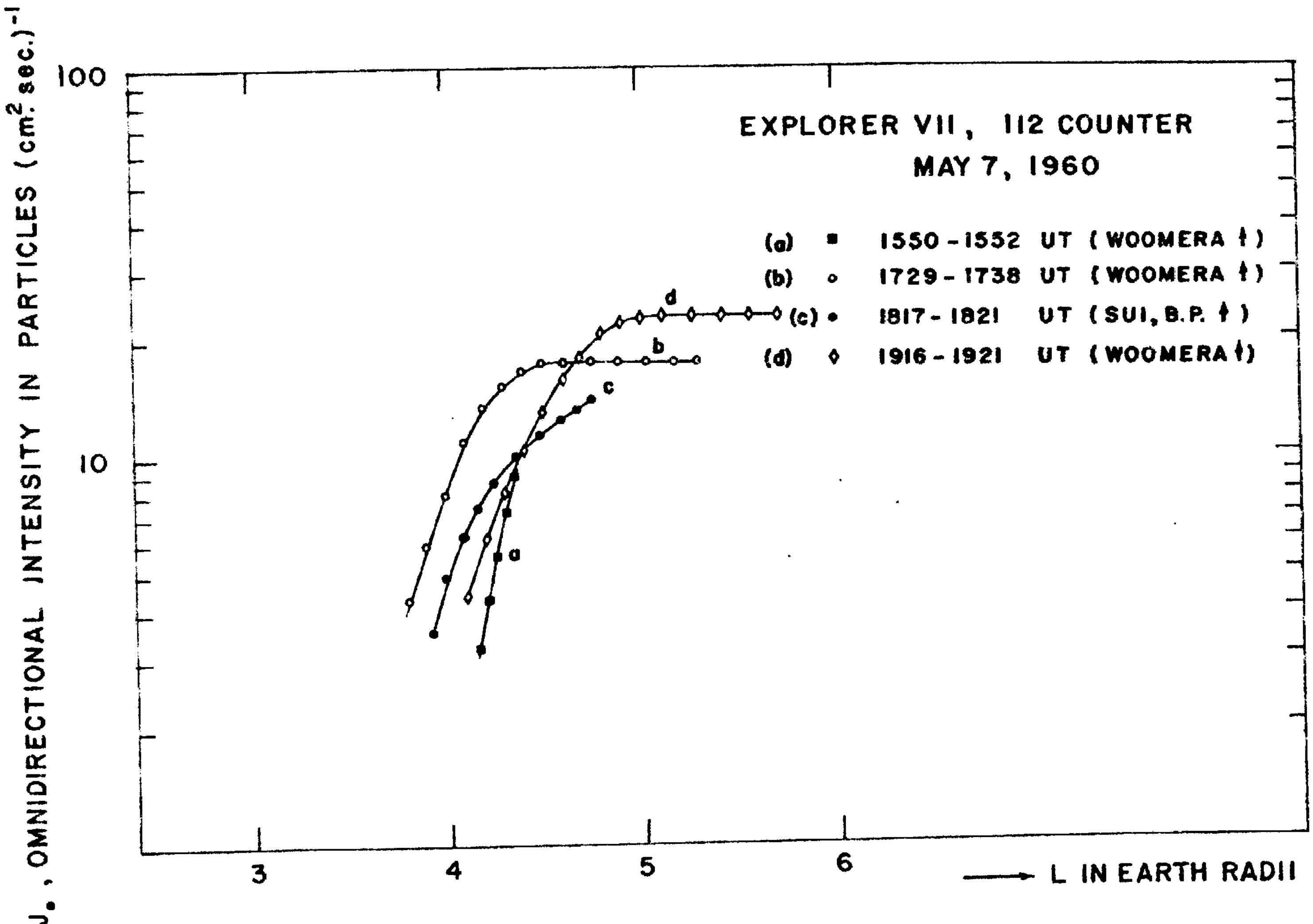

EXPLORER VII, 112 COUNTER
MAY 5, 1960
(a) ○ 1817 - 1823 UT (WOOMERA ↑)
(b) ■ 1903 - 1907 UT (SUI ↑)
(c) △ 2000 - 2008 UT (WOOMERA ↑)
MAY 6, 1960
(d) ▲ 1608 - 1613 UT (WOOMERA ↓)
(e) □ 1839 - 1845 UT (SUI, OTTAWA ↑)
(f) ● 2021 - 2030 UT (SUI, B.P. ↑)
NOV. 22, 1960
(g) ◇ 0017 - 0023 UT (WOOMERA ↑)
a
b
c
d
e
f
g
100
10
3
4
5
6
J₀, OMNIDIRECTIONAL INTENSITY IN PARTICLES (cm.² sec.)⁻¹
⟶ L IN EARTH RADII

FIG. 20



EXPLORER VII, 112 COUNTER
MAY 7, 1960
(a) ■ 1550 - 1552 UT (WOOMERA ↓)
(b) ○ 1729 - 1738 UT (WOOMERA ↓)
(c) ● 1817 - 1821 UT (SUI, B.P. ↓)
(d) ◇ 1916 - 1921 UT (WOOMERA ↓)
a
b
c
d
100
10
3
4
5
6
→ L IN EARTH RADII
J_0, OMNIDIRECTIONAL INTENSITY IN PARTICLES $(cm^2 sec.)^{-1}$

FIG. 21

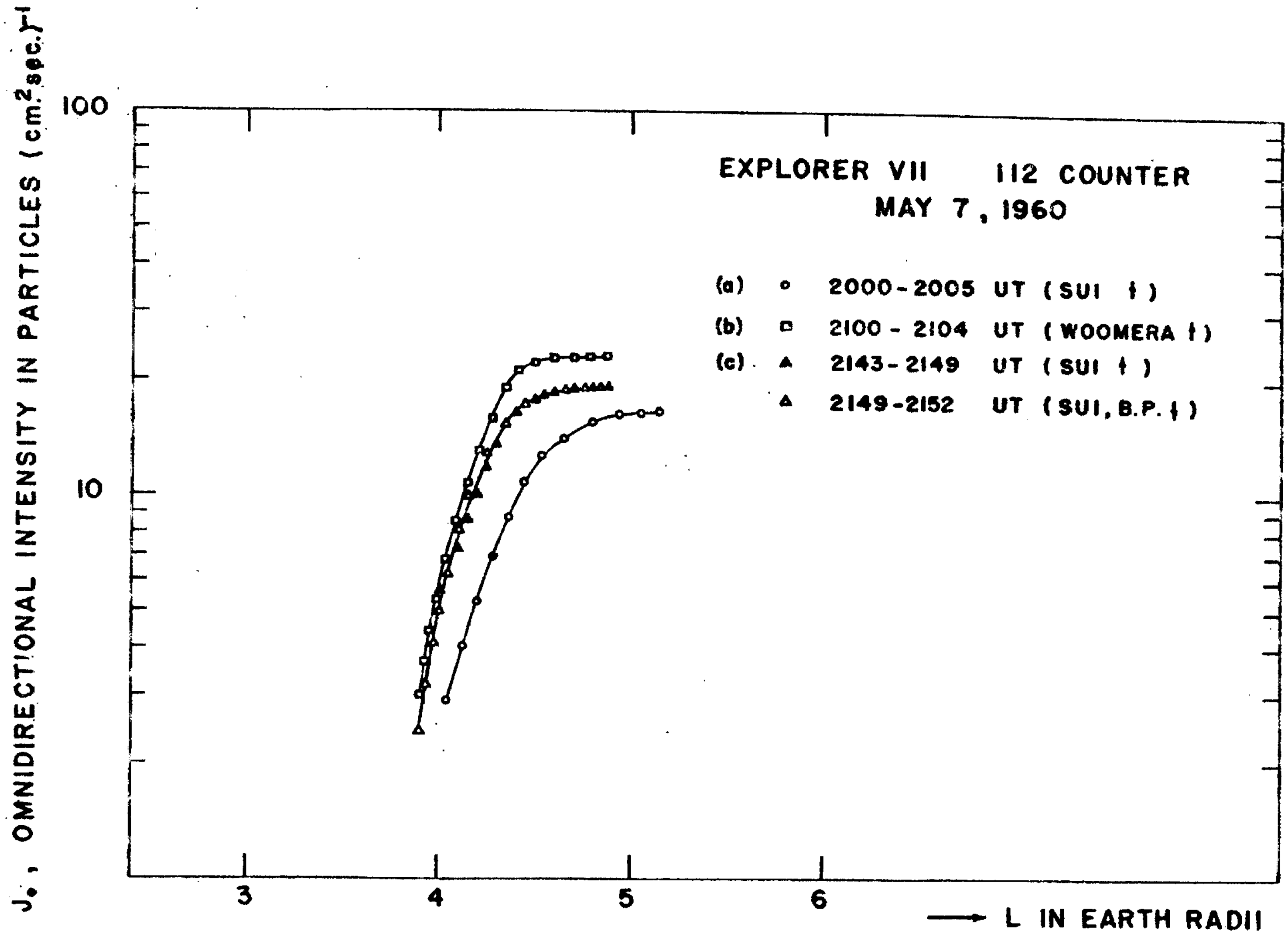

EXPLORER VII 112 COUNTER
MAY 7, 1960
(a) ○ 2000-2005 UT (SUI ↓)
(b) □ 2100 - 2104 UT (WOOMERA ↓)
(c) ▲ 2143-2149 UT (SUI ↓)
△ 2149-2152 UT (SUI, B.P. ↓)
J_o, OMNIDIRECTIONAL INTENSITY IN PARTICLES $(cm.^2 sec.)^{-1}$
100
10
3
4
5
6
→ L IN EARTH RADII

FIG. 22

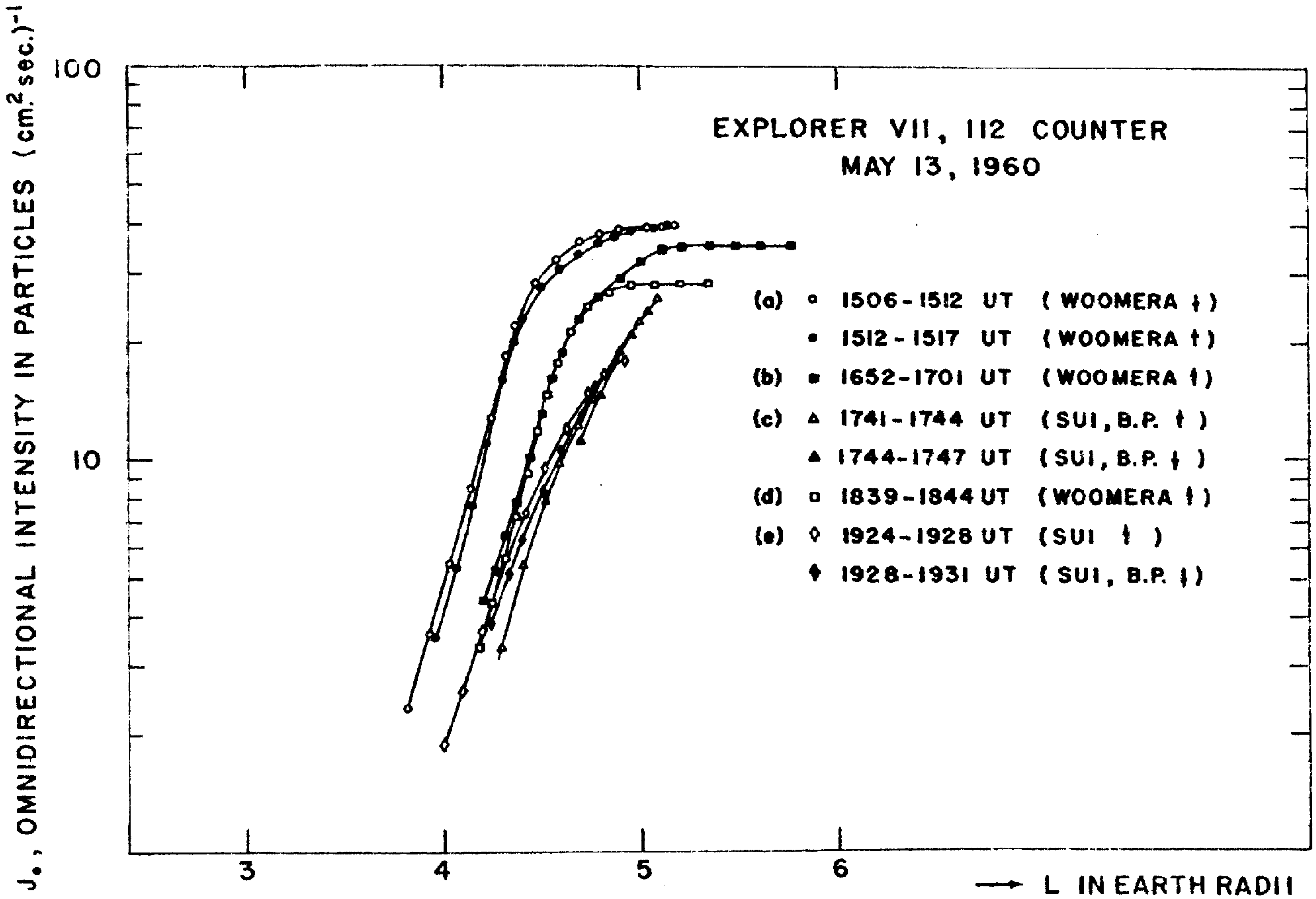

EXPLORER VII, 112 COUNTER
MAY 13, 1960
(a) ○ 1506-1512 UT (WOOMERA ↓)
● 1512-1517 UT (WOOMERA ↑)
(b) ■ 1652-1701 UT (WOOMERA ↑)
(c) △ 1741-1744 UT (SUI, B.P. ↑)
▲ 1744-1747 UT (SUI, B.P. ↓)
(d) □ 1839-1844 UT (WOOMERA ↑)
(e) ◇ 1924-1928 UT (SUI ↑)
◆ 1928-1931 UT (SUI, B.P. ↓)
100
10
3
4
5
6
J₀, OMNIDIRECTIONAL INTENSITY IN PARTICLES (cm.² sec.)⁻¹
→ L IN EARTH RADII

FIG. 23

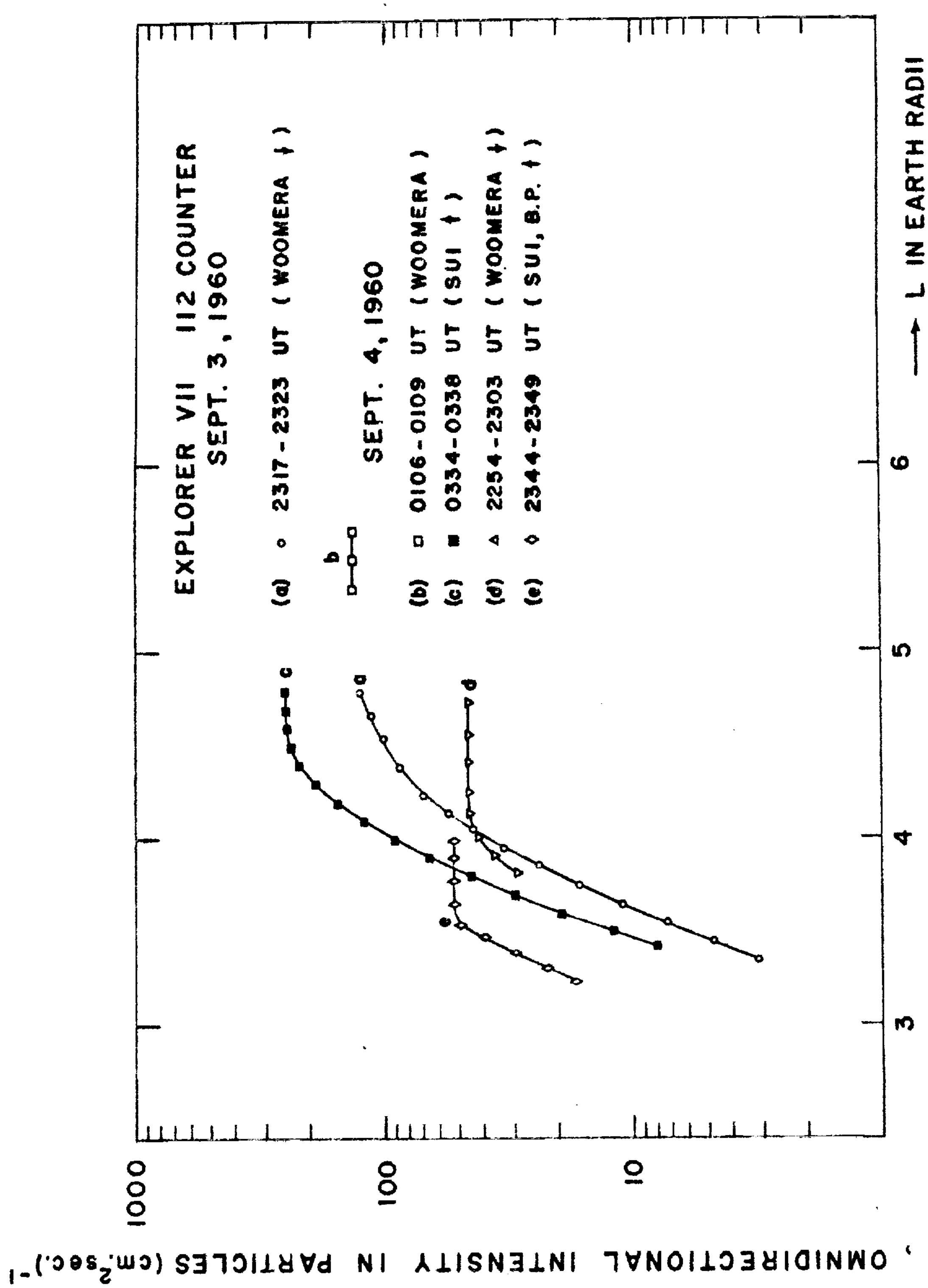

EXPLORER VII 112 COUNTER
SEPT. 3, 1960
(a) 2317-2323 UT (WOOMERA)
b
SEPT. 4, 1960
(b) 0106-0109 UT (WOOMERA)
(c) 0334-0338 UT (SUI)
(d) 2254-2303 UT (WOOMERA)
(e) 2344-2349 UT (SUI, B.P.)
a
b
c
d
e
1000
100
10
3
4
5
6
L IN EARTH RADII
J0, OMNIDIRECTIONAL INTENSITY IN PARTICLES (cm2sec.)-1

FIG. 24

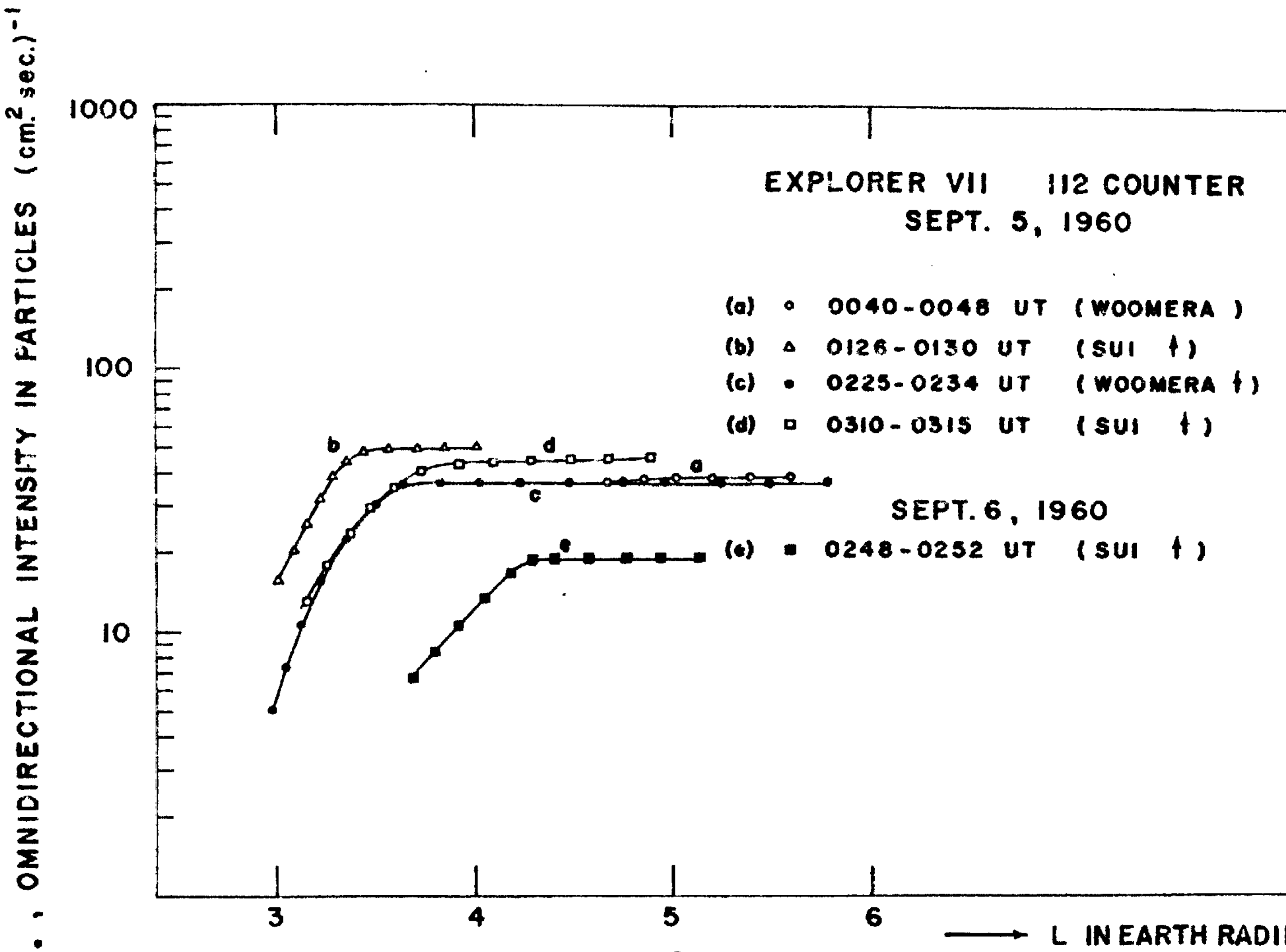

EXPLORER VII 112 COUNTER
SEPT. 5, 1960
(a) ○ 0040-0048 UT (WOOMERA)
(b) △ 0126-0130 UT (SUI ↑)
(c) ● 0225-0234 UT (WOOMERA ↑)
(d) □ 0310-0315 UT (SUI ↑)
SEPT. 6, 1960
(e) ■ 0248-0252 UT (SUI ↑)
a
b
c
d
e
1000
100
10
3
4
5
6
J, OMNIDIRECTIONAL INTENSITY IN PARTICLES (cm.² sec.)⁻¹
→ L IN EARTH RADII

FIG. 25

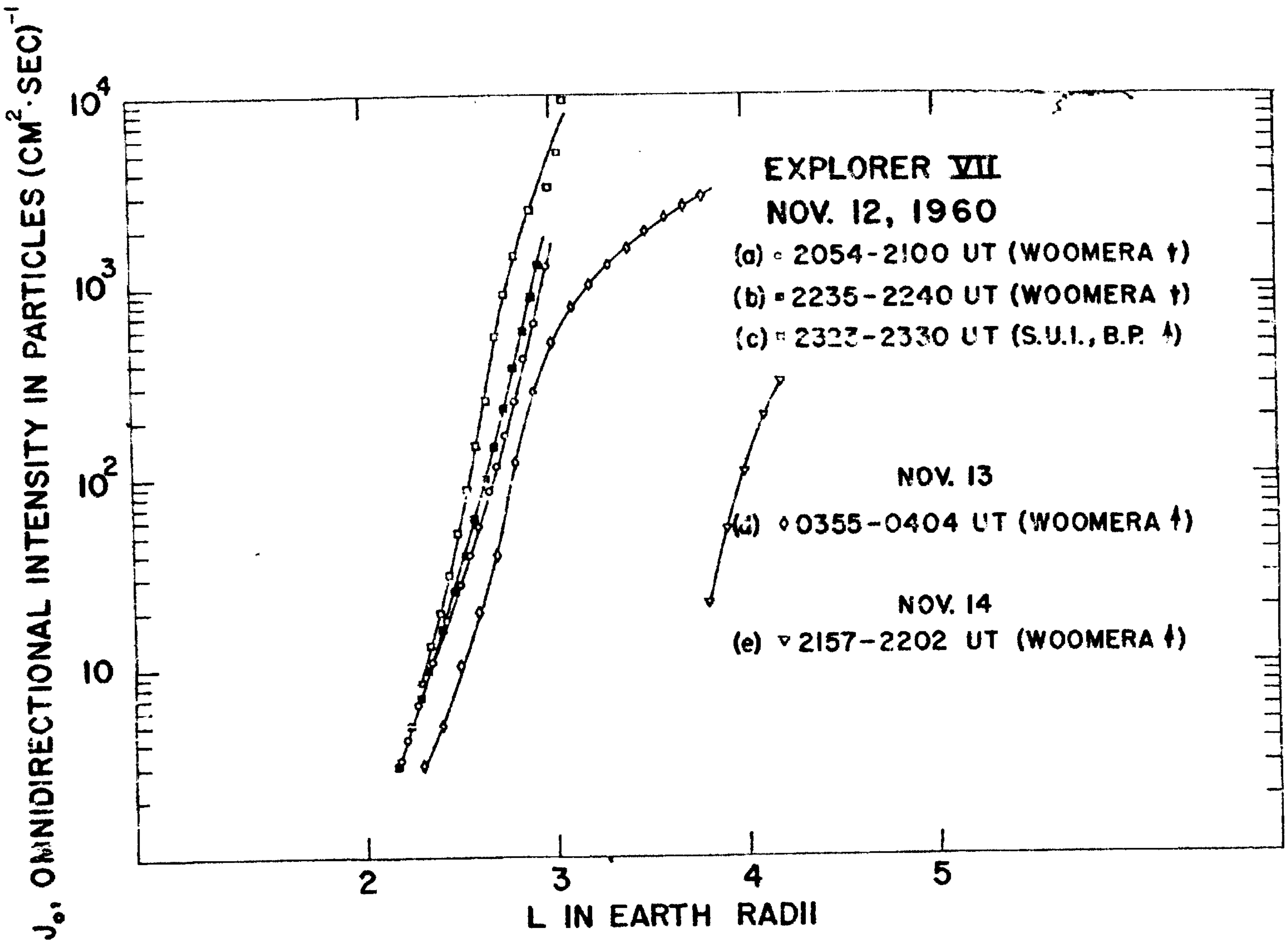

EXPLORER VII
NOV. 12, 1960
(a) ○ 2054-2100 UT (WOOMERA ↑)
(b) ■ 2235-2240 UT (WOOMERA ↑)
(c) □ 2323-2330 UT (S.U.I., B.P. ↑)
NOV. 13
(d) ◊ 0355-0404 UT (WOOMERA ↑)
NOV. 14
(e) ▽ 2157-2202 UT (WOOMERA ↑)
J_0, OMNIDIRECTIONAL INTENSITY IN PARTICLES $(CM^2 \cdot SEC)^{-1}$
10^4
10^3
10^2
10
2
3
4
5
L IN EARTH RADII

FIG. 26

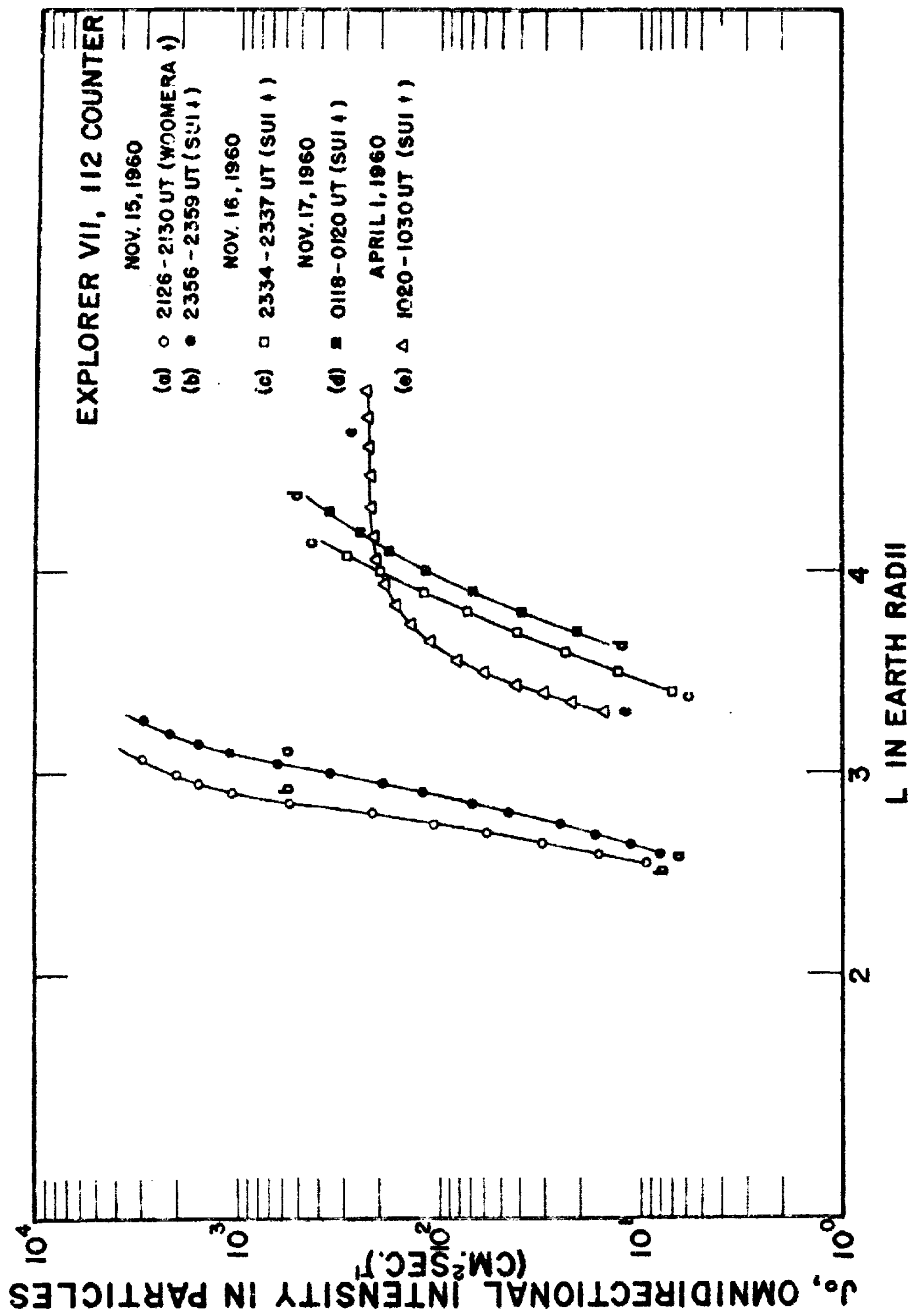

EXPLORER VII, 112 COUNTER
NOV. 15, 1960
(a) ○ 2126 - 2130 UT (WOOMERA 1)
(b) ● 2356 - 2359 UT (SUI 4)
NOV. 16, 1960
(c) □ 2334 - 2337 UT (SUI 4)
NOV. 17, 1960
(d) ■ 0118 - 0120 UT (SUI 4)
APRIL 1, 1960
(e) △ 1020 - 1030 UT (SUI 1)
J₀, OMNIDIRECTIONAL INTENSITY IN PARTICLES (CM.² SEC.)⁻¹
L IN EARTH RADII

FIG. 27

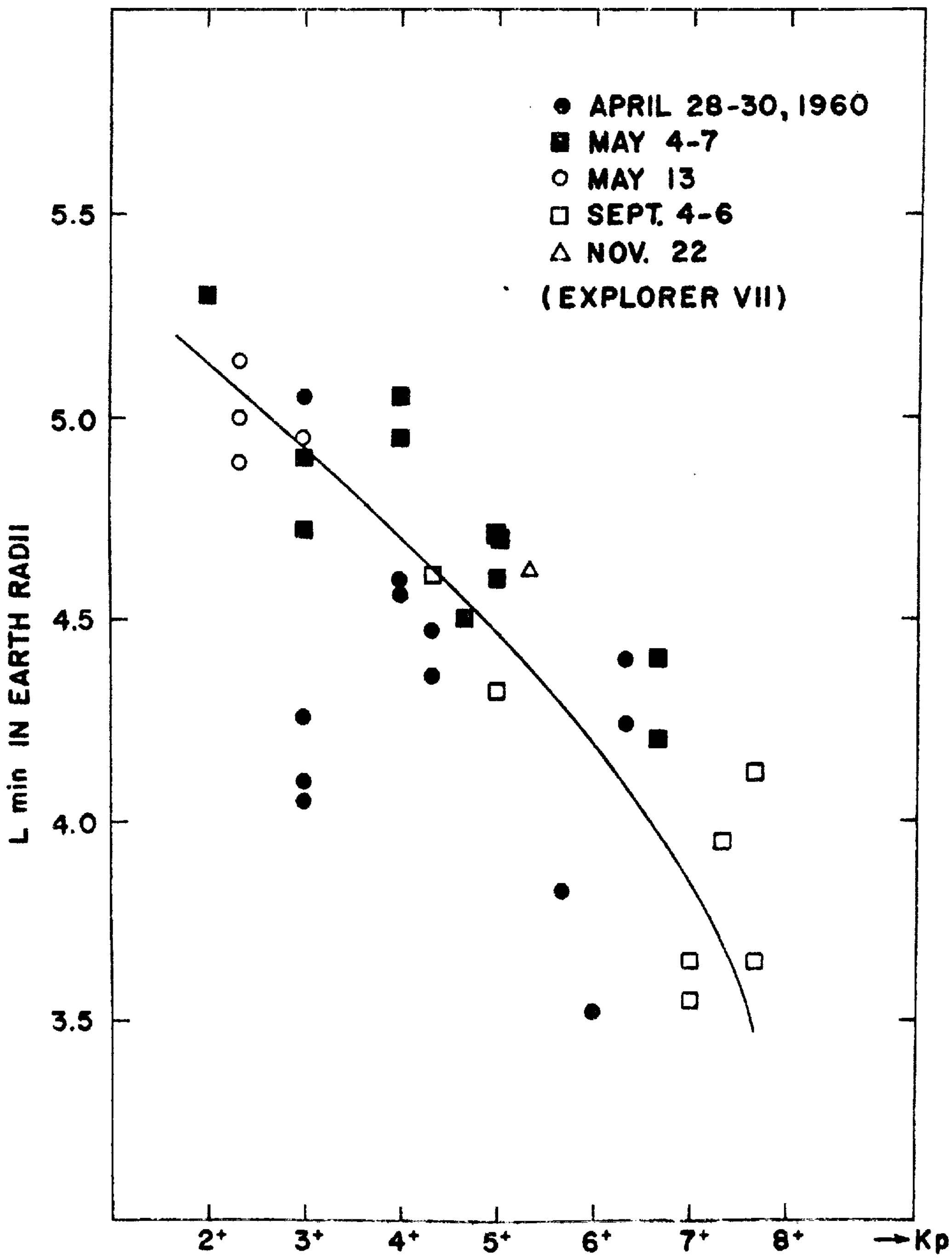
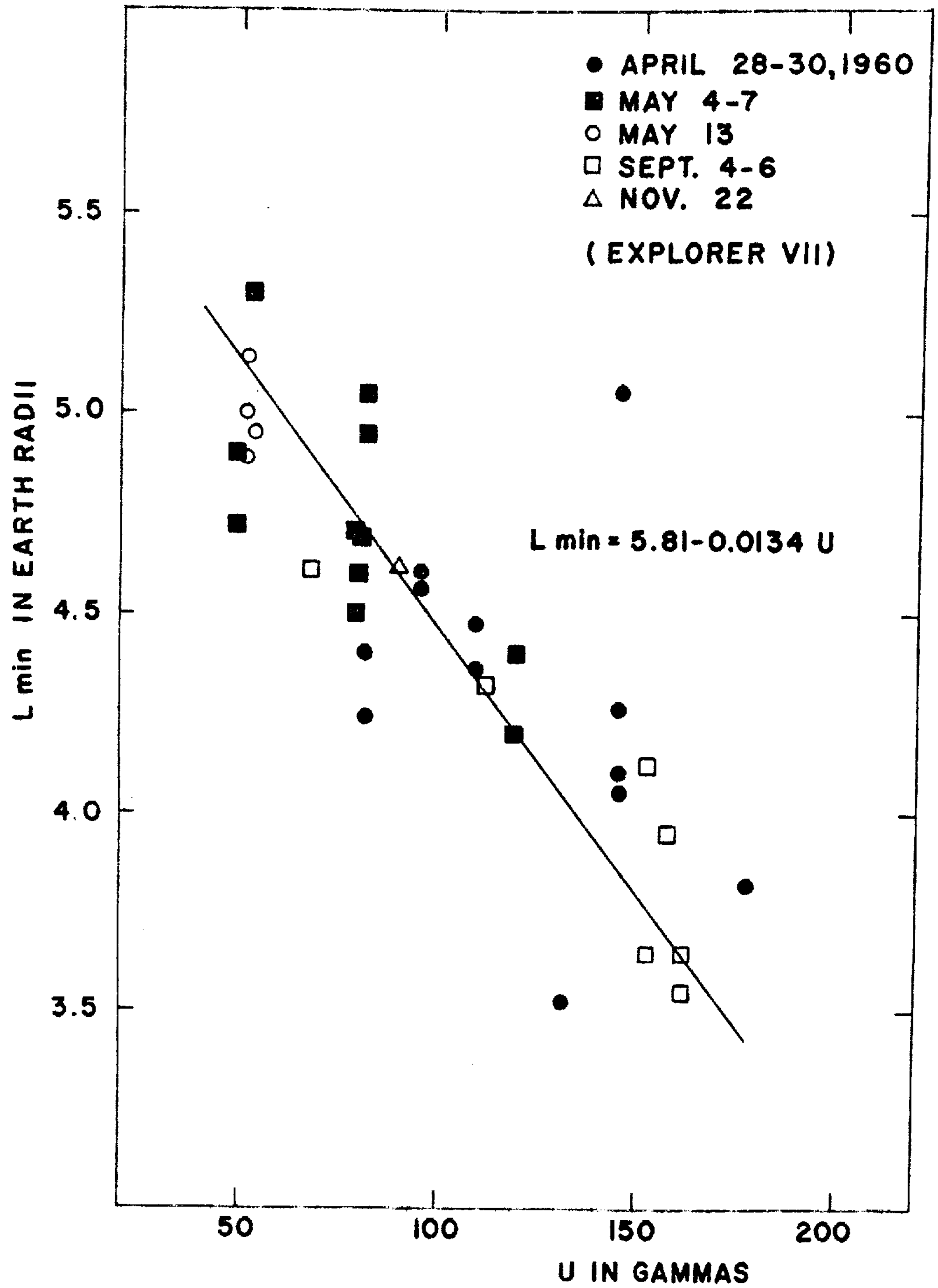
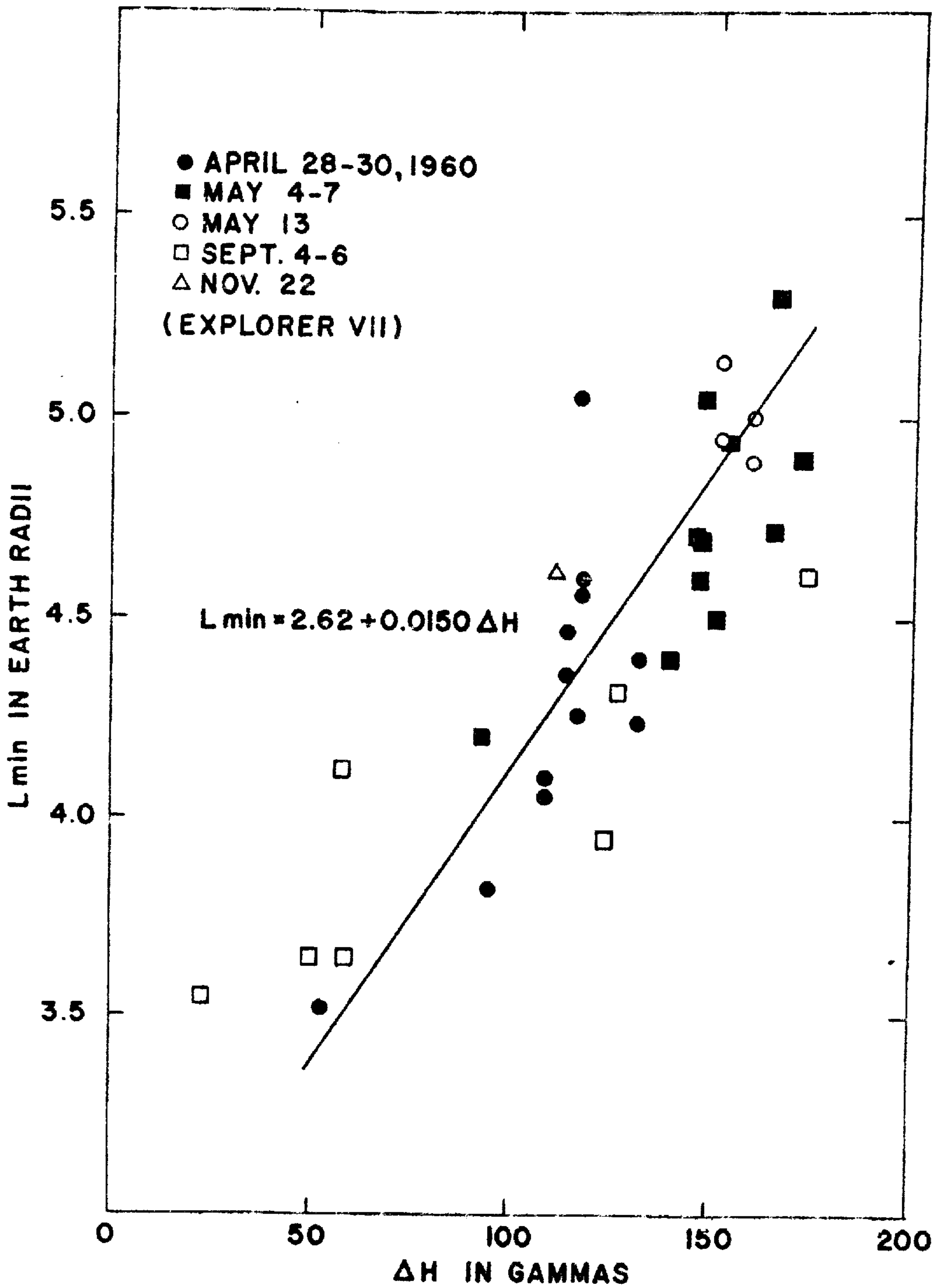

● APRIL 28-30, 1960
■ MAY 4-7
○ MAY 13
□ SEPT. 4-6
△ NOV. 22
(EXPLORER VII)
5.5
5.0
4.5
4.0
3.5
L min IN EARTH RADII
2+
3+
4+
5+
6+
7+
8+
→Kp

FIG. 28



● APRIL 28-30,1960
■ MAY 4-7
○ MAY 13
□ SEPT. 4-6
△ NOV. 22
(EXPLORER VII)
L min = 5.81-0.0134 U
L min IN EARTH RADII
5.5
5.0
4.5
4.0
3.5
50
100
150
200
U IN GAMMAS

FIG. 29



HORIZONAL INTENSITY AT TUCSON EQUALS
(25,750 + ΔH) GAMMAS

FIG. 30

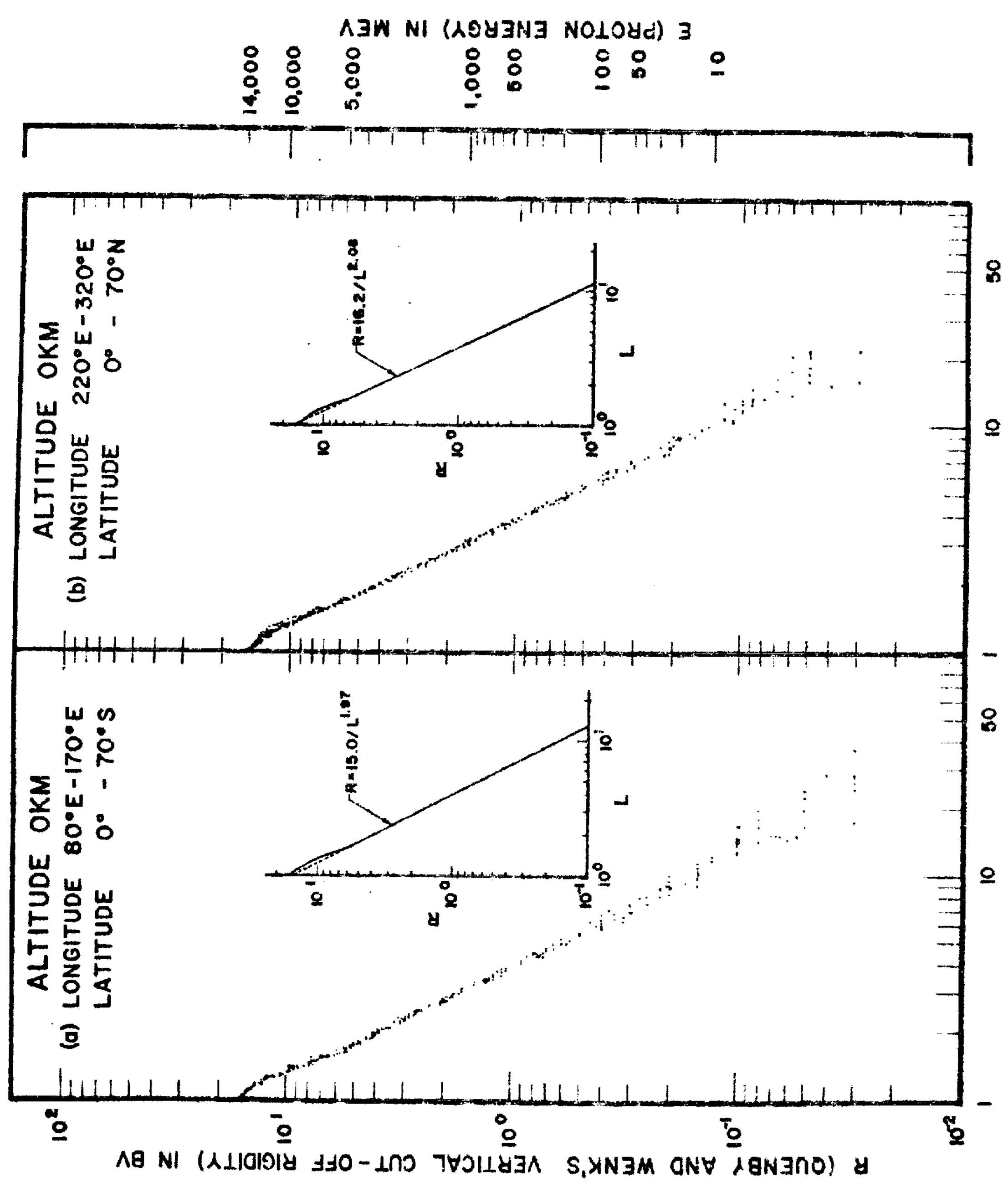

ALTITUDE OKM
(a) LONGITUDE 80°E-170°E
LATITUDE 0° - 70°S
ALTITUDE OKM
(b) LONGITUDE 220°E-320°E
LATITUDE 0° - 70°N
R=15.0/L^1.97
R=16.2/L^2.08
L IN EARTH RADII
R (QUENBY AND WENK'S VERTICAL CUT-OFF RIGIDITY) IN BV
E (PROTON ENERGY) IN MEV

FIG. 31